MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY.

VOL. LXXIX. APRIL 11, 1919. No. 6.

Professor A. FOWLER, F.R.S., PRESIDENT, in the Chair.

Denis Arthur Casey, D.Sc., Lieut. R.N.R., Clonmel, Co. Tipperary, Ireland;

Capt. Henry Percy Douglas, C.M.G., R.N., Assistant Hydrographer, Admiralty, Whitehall, London, S.W. 1;

Henry Reginald Fry, B.A. (Cantab.), Hadley Hurst, Barnet;

William Thomas Gayfer, Rose Villa, Frederick Street, Cleethorpes;

Commander George Robinson Hudson, R.D.R.N.R., D.T.C., Royal Naval Barracks, Portsmouth; and 14 Merton Road, Southsea, Hants;

Henry Francis Jackson, Captain, R.A.F., Member of the Royal Aeronautical Society and of the Society of Engineers, Rugby Hotel, Euston Grove, London, N.W. 1;

Prafulla Chandra Jotirbhusan, Professor of Astronomy, Free Sanscrit College, 2 Ramanath Mazundar Street, Calcutta;

The Rev. Harold Pain, M.A., St. Andrew's Vicarage, Norway, Eastbourne;

Edward Prentice, St. Mary's Lodge, Ashtead, Surrey;

Sir William Napier Shaw, F.R.S., 10 Moreton Gardens, London, S.W. 5;

George Neville Watson, M.A., Sc.D., Professor of Mathematics in the University of Birmingham, The University, Edmund Street, Birmingham; and

James Bruce Williamson, M.A., F.R.Met.Soc., Southcliffe, Ventnor, Isle of Wight.

were balloted for and duly elected Fellows of the Society.

The following candidate was proposed for election as a Fellow of the Society, the name of the proposer from personal knowledge being appended:—

Ignatius Nicholas Dracopoli, F.R.G.S., Captain in the Special Reserve of Officers, now Engineer in the employ of J. Whittall & Co., 9 Fenchurch Street, E.C. 3 (proposed by E. A. Reeves).

Dr. Vesto Melvin Slipher, Director of the Lowell Observatory, Flagstaff, Arizona, U.S.A.,

was proposed by the Council as an Associate of the Society.

Fifty presents were announced as having been received since the last meeting, including, among others:

Photographs taken with the 72-inch Canadian Reflector (four transparencies), presented by Dr. H. S. Plaskett.

The Origin of Binary Systems.

By J. H. Jeans.

1. In a recent paper* it was suggested that the orbits of the older binary systems might have been so much pulled or knocked about by the gravitational forces from other stars as to have reached something at least approximating to a final state of equipartition of energy. This suggestion can be tested by determining the laws of distribution of eccentricities and periods of orbits in the ideal steady state, and comparing it with the distribution observed in binary systems.

Determination of Laws of Distribution of Eccentricities and Periods.

2. Let M, M′ be the masses of the two components of a binary system. At any instant let r be their distance apart, and let the velocity of either relative to the other have components α, β, γ along any three rectangular axes in space. The law of distribution of r, α, β, γ in the final state of equipartition of energy is known to be†

$$A\, exp\left[-H\frac{MM'}{M+M'}(\alpha^2+\beta^2+\gamma^2)+2H\frac{GMM'}{r}\right]d\alpha d\beta d\gamma 4\pi r^2 dr \qquad (1)$$

* "The Evolution of Binary Systems," *M.N.*, 79, 100.

† *Dynamical Theory of Gases* (2nd edn.), p. 202.

while the law of distribution of u, v, w, the components of velocity of the centre of gravity in space, is

$$B\,exp\,[-H(M+M')(u^2+v^2+w^2)]dudvdw \quad . \quad (2)$$

Here A, B are constants, G is the gravitation constant, and H replaces the usual h of the kinetic theory of gases, being such that if C is the mean-square velocity in space of all systems of mass $M+M'$,

$$C^2=\frac{3}{2H(M+M')} \quad . \quad . \quad . \quad . \quad (3)$$

Formula (1) is of course invariant as regards different directions of the axes in space. Let α be measured in the direction of r increasing, so that α becomes identical with $\dot{r}$, the radial velocity. Then $\beta^2+\gamma^2$ is the square of the tangential velocity τ. Let τ be measured always positively and let ϕ be the azimuth of its direction. Thus $\beta^2+\gamma^2$ may be replaced by τ^2, and $d\beta d\gamma$ by $\tau d\tau d\phi$. Making these substitutions, and integrating with respect to ϕ, formula (1) becomes

$$8\pi^2A\,exp\left[-H\frac{MM'}{M+M'}(\dot{r}^2+\tau^2)+2H\frac{GMM'}{r}\right]d\dot{r}\tau d\tau r^2dr\,. \quad (4)$$

Let us put

$$K=H\frac{MM'}{M+M'},\ \mu=G(M+M'),\ E=\tfrac{1}{2}(\dot{r}^2+\tau^2)-\frac{\mu}{r} \quad . \quad (5)$$

The relative orbit is the same as would be described by a single particle moving about a fixed centre of force μ/r^2, and the energy of its motion per unit mass would be E. Using the symbols just introduced, formula (4) can be written

$$8\pi^2Ae^{-2KE}d\dot{r}\tau d\tau r^2dr \quad . \quad . \quad . \quad (6)$$

In this law of distribution r can range from 0 to ∞, τ from 0 to ∞, and $\dot{r}$ from $-\infty$ to $+\infty$. Values of r, $\dot{r}$, and τ, which make E positive, correspond to pairs of stars describing hyperbolic orbits in temporary encounter; to study permanent binary systems the values of r, $\dot{r}$, and τ must be limited to those which make E negative.

The rate of description of double areas, h, is equal to $r\tau$. Let us put

$$k=\frac{1}{r\tau},\quad \sigma=\tau-\frac{\mu}{r\tau} \quad . \quad . \quad . \quad . \quad (7)$$

In formula (6) transform the variables from $\dot{r}$, τ, r to E, k, σ, the relations between the old and new variables being given by equations (5) and (7). On forming and simplifying the Jacobian modulus of transformation, we obtain

$$\frac{\partial(E,\,k,\,\sigma)}{\partial(\dot{r},\,\tau,\,r)}=\frac{\dot{r}}{r^2\tau},$$

so that

$$d\dot{r}\tau d\tau r^2 dr = \frac{\tau^2 r^4}{\dot{r}} dE dk d\sigma \quad . \quad . \quad . \quad (8)$$

Solving equations (5) and (7) explicitly for r, τ, $\dot{r}$ so as to express the old variables in terms of the new, we find

$$\tau = \sigma + \mu k, \quad r = \frac{1}{k(\sigma + \mu k)} \quad . \quad . \quad . \quad (9)$$

$$\dot{r} = \left[2E + \mu^2 k^2 - \sigma^2\right]^{\frac{1}{2}} \quad . \quad . \quad . \quad (10)$$

From equation (9) it is clear that the range from $r = 0$ to ∞ and from $\tau = 0$ to ∞ is exactly represented by allowing both k and $\sigma + k\mu$ to vary from 0 to ∞. The range in which $\dot{r}$ varies from $-\infty$ to $+\infty$ will be represented by letting E vary from $\frac{1}{2}(\sigma^2 - \mu^2 k^2)$ to $+\infty$, and this range must be taken twice over, once to represent positive values of $\dot{r}$ and once to represent negative values of $\dot{r}$.

Thus, with the help of relations (8), (9), and (10), we find that the new law of distribution, replacing (4), must be

$$\frac{16\pi^2 A}{(\sigma + \mu k)^2 k^4 \left[2E + \mu^2 k^2 - \sigma^2\right]^{\frac{1}{2}}} e^{-2KE} dE dk d\sigma \quad . \quad (11)$$

in which k can have all positive values, σ can have all values from $-k\mu$ to ∞, but E varies only from $\frac{1}{2}(\sigma^2 - \mu^2 k^2)$ to ∞.

If we wish to limit the law so as to represent only permanent binary systems, E must be negative. Thus in the three-dimensional space in which E, k, σ are taken as rectangular co-ordinates, permanent binary systems will be represented in a space bounded by the parabolic hyperboloid

$$2E + \mu^2 k^2 - \sigma^2 = 0 \quad . \quad . \quad . \quad . \quad (12)$$

and the three planes, $E = 0$, $k = 0$, $\sigma + k\mu = 0$, only that octant of the space being considered in which k and $\sigma + k\mu$ are positive, while E is negative.

Let us now assign a definite negative value to E and a definite positive value to k and integrate with respect to σ. It will only be when $\mu^2 k^2 + 2E$ is positive that the law of distribution will exist for any value of σ at all; when this is the case, the limits for σ determined by equation (12) are $\sigma = \pm\left[\mu^2 k^2 + 2E\right]^{\frac{1}{2}}$. Since $\sigma + \mu k$ is positive throughout this range, it is clear that these limits determine the correct range of integration. Write

$$\mu^2 k^2 + 2E = p^2, \quad \sigma = p \cos\theta \quad . \quad . \quad . \quad (13)$$

then the limits of integration are from $\theta = 0$ to $\theta = \pi$. The integrated law of distribution becomes

$$16\pi^2 A \int_0^{\pi} \frac{d\theta}{(p\cos\theta + \mu k)^2} e^{-2KE} dE \frac{dk}{k^4} \quad . \quad . \quad (14)$$

Since $k = 1/h$, this formula gives the law of distribution of values of E and h. It is easily transformed so as to give the law of distribution of eccentricity ϵ and period P.

The eccentricity ϵ is given by

$$\epsilon = \left[1 + \frac{2Eh^2}{\mu^2}\right]^{\frac{1}{2}} = \left[1 + \frac{2E}{k^2\mu^2}\right]^{\frac{1}{2}} = \frac{p}{k\mu} \quad . \quad . \quad (15)$$

Replacing p by $\epsilon k\mu$ and effecting the integration with respect to θ, formula (14) becomes

$$16\pi^3 A(1-\epsilon^2)^{-\frac{3}{2}} e^{-2KE/l} \frac{dEdk}{\mu^2 k^6} \quad . \quad . \quad . \quad (16)$$

The variables can now be changed from E, k to E, ϵ. From equation (15) the modulus of transformation is given by

$$\epsilon d\epsilon dE = -\frac{2E}{k^3\mu^2} dk dE,$$

so that formula (16) becomes

$$16\pi^3 A\mu^3 e^{-2KE}(-2E)^{-\frac{6}{2}} dE\epsilon d\epsilon \quad . \quad . \quad (17)$$

The period P is a function of E only. If a is the semi-major axis of the orbit,

$$-2E = \mu/a, \quad P = 2\pi\mu^{-\frac{1}{2}} a^{\frac{3}{2}}$$

so that

$$-2E = (2\pi\mu/P)^{\frac{2}{3}} \quad . \quad . \quad . \quad (18)$$

and, restoring the values of K and μ from equation (5), the law of distribution (17) becomes

$$\frac{8}{3}\pi^2 A\mu^2 exp\left[\frac{HMM'}{(M+M')^{\frac{1}{3}}}\left(\frac{2\pi G}{P}\right)^{\frac{2}{3}}\right] dP(2\epsilon d\epsilon) \quad . \quad (19)$$

The form of this law shows that in the final steady state there is no correlation between the values of ϵ and P. Whatever the values of E or P, the law of distribution of eccentricities is the simple law

$$2\epsilon d\epsilon, \quad . \quad . \quad . \quad . \quad . \quad (20)$$

so that all values of ϵ^2 are equally probable. Also, regardless of the eccentricity of the orbit, the law of distribution of periodic times P is

$$\frac{8}{3}\pi^2 A\mu^2 exp\left[\frac{HMM'}{(M+M')^{\frac{1}{3}}}\left(\frac{2\pi G}{P}\right)^{\frac{2}{3}}\right] dP \quad . \quad . \quad (21)$$

We obtain the total number of systems by integrating from $P = 0$ to $P = \infty$. The integral, however, is seen to be divergent at both limits; for a finite number of systems, $A = 0$. In other words, all except an infinitesimal minority of the systems are in

configurations in which the constituents are either infinitely close together ($P = o$) or infinitely far apart ($P = \infty$).

Discussion of Results.

3. We have examined what law of distribution would ultimately prevail in the periods and eccentricities of binary systems whose orbits had been perturbed indefinitely by the gravitational attractions from other stars. We have found that, in this ideal final state,

(i) there would be no correlation between period and eccentricity,
(ii) the eccentricities would be distributed according to the the law *2ede*—in other words, all values of e^2 would be equally likely,
(iii) the periods would conform to the law of distribution (21).

It is at once clear that the system of binary stars is still far removed from its equipartition state. The available observational material has recently been collected by Aitken;* there is pronounced correlation between eccentricity and period, and neither eccentricities nor periods conform, even approximately, to the theoretical laws.

If the theoretical equipartition laws had been found to be obeyed perfectly, we should have obtained a concise and highly significant result, but it would have been impossible to progress any further: the investigation would be ended. As things are, a study of the departures from the law of equipartition may be expected to yield valuable information as to the origins and past history of the binary systems. If, for instance, we find the number of systems having any values of e and P to be greatly in excess over that required by the law of distribution, we should naturally suppose that in the initial states of binary systems these values were largely in excess. Thus if a system of binaries had originated by fission, we should expect to find an excess of small values of e and of small values of P. If a system of binaries had originated by capture, we should expect to find an excess of values of e nearly equal to unity and also an excess of large values of P. If a system of binaries had originated out of independent nuclei in the original nebula, we should expect to find an excess of systems of period about equal to that of two such nuclei revolving about one another in contact.

4. Let us consider first the law of distribution of eccentricities. Aitken tabulates the eccentricities of 119 spectroscopic binaries. Dividing the whole range from $e = o$ to $e = 1$ into five equal ranges (o to o·2, o·2 to o·4, etc.), the number in these ranges are respectively 86, 18, 16, 6, 1. If the theoretical law were obeyed, the numbers of stars within these ranges would be in the ratio

* *The Binary Stars* (New York, 1918).

1 : 3 : 5 : 7 : 9. Clearly the theoretical law is not obeyed at all; there is an enormous excess of systems of small eccentricity, pointing to an origin in which the systems revolved in nearly circular orbits. Combining this with other evidence, the distribution of eccentricities may be said to point to fission as the origin of the majority of spectroscopic binaries.

Aitken tabulates the eccentricities of 87 visual binaries.* The numbers falling in the five ranges before considered are 7, 20, 35, 17, 8. If the theoretical law were obeyed, these numbers would be in the ratio 1 : 3 : 5 : 7 : 9, say 7, 21, 35, 49, 63. The agreement up to $e = 0{\cdot}60$ is very good, but there is no agreement beyond; some of the agreement even up to $e = 0{\cdot}60$ is accidental, for it is lessened by further subdivision of the ranges for e. There is a marked deficiency above $e = 0{\cdot}60$, but no excess for small values of e.

There seems to be no reason why the 87 binaries in question should not form a tolerable sample of all visual binaries as regards distribution of eccentricities. They naturally do not present a fair sample as regards periods, for binaries of both long and short periods are likely to escape detection, but the correlation between eccentricity and period is not very marked in the case of visual binaries. Before attempting to unravel the meaning of the distribution of eccentricities, it will be well to consider the distribution of periods.

5. We may exclude B-type binaries from the discussion altogether. Not a single visual binary of B-type is known. Of the spectroscopic binaries, only two (Algol and χ Aurigæ) have periods greater than a year. The vast majority are of short period and low eccentricity, and their origin may, without much doubt, be ascribed to fission of comparatively recent date.

Binary systems of types other than B are sufficiently similar to one another in mass and mass-ratio for it to be permissible to assume uniform values of M and M′. Let us take $M = M' = 1{\cdot}7 \times 10^{33}$ gms., then the law of distribution (21) becomes

$$D\, exp\,[H(M + M')(4 \times 10^{14})P^{-\frac{8}{3}}]dP,$$

where D is a constant and P is measured in days. If we assume the mean stellar velocity of all these systems to be 20 kms. a second, then equation (3) gives $H(M + M') = 3{\cdot}75 \times 10^{-13}$, and the law becomes

$$D\, exp\,[150P^{-\frac{8}{3}}]dP \quad . \quad . \quad . \quad (22)$$

where P is still measured in days.

When P = 30 years, $150P^{-\frac{8}{3}} = 0{\cdot}3$. Thus when P is greater than about 30 years, formula (22) may, with a rough approximation to accuracy, be replaced by $D dP$. Thus the periods over about 30 years are uniformly distributed. For smaller periods the exponential in formula (22) measures the ratio of "period-density" to that

* I have included 19 less good determinations; if these are omitted, the agreement with the law *zede* is less good.

for large periods. When P is small this factor becomes enormously great, as is shown by the following values:

$$P = 1 \text{ year, factor} = exp(2{\cdot}95) = 19{\cdot}1.$$
$$P = 30 \text{ days, factor} = exp(15{\cdot}6) = 5{,}950{,}000.$$
$$P = 10 \text{ days, factor} = exp(32{\cdot}4) = 117 \times 10^{12}.$$

Thus in the final state the periods of orbits crowd to an extraordinary degree into the range of small values. Corresponding to one star of period between 30 years and 1000 years there ought to be about 17 with periods between 30 and 31 days, and about 320,000,000 with periods between 10 and 11 days. There ought also to be an infinite number with periods over 1000 years.

In the previous paper (equation (6)) it was found that the balance between the orbital motion and translatory motion which is required by the theorem of equipartition is attained when (approximately) $P = G(M + M')/C^3$. With the values we have assumed ($M + M' = 3{\cdot}4 \times 10^{33}$, $C = 20$ kms. a sec.) this critical value of P is almost exactly one year. Thus encounters with other stars tend on the whole to increase P when it is less than a year, but to decrease P when it is greater than a year. The law of distribution (22) may be regarded as representing a distribution about a mean value $P = 1$ year, *but with infinite dispersion.* In the final state, a system of stars would fall into two approximately equal classes—those of period greater than a year, in which the average period would be very great; and those of period less than a year, in which the average period would be very small.

6. It is excessively difficult to compare these theoretical results with observation. So far as present observations go, the binary stars happen to fall into two approximately equal classes, of periods greater and less than a year and with enormous dispersion about this median value. These two classes coincide very approximately with the classes of spectroscopic and visual binaries.

But it is very improbable that the known binaries form a fair sample of the whole; the two classes probably correspond to the two available methods of discovery, rather than to any natural division. Binaries of period about equal to one year would be apt to escape detection by both methods. On the other hand, within the ranges within which detection ought to be easy, there is distinct evidence of the accumulation towards long and short periods.

On the assumption that the known binaries form a fair sample of the whole, their distribution, both in periods and eccentricity, approximates to what might be expected on the assumption that they had originated by fission; the long period binaries, which would have been most disturbed by encounters, ought to approximate fairly to the law of distribution *zede* of eccentricities, and it has been seen that to some extent they do. But against this there is a pronounced deficiency of orbits of short period and high eccentricity.

We are much more likely to obtain a fair sample by con-

sidering only stars so near to us that all binaries may reasonably be assumed to be known. Of the nineteen stars tabulated by Eddington * as being known to be within 5 parsecs of the Sun, nine are certainly binary. The only five of which the periods are known all have periods between 30 and 1000 years, the periods being approximately 39, 50, 55, 80, and 500 years. Now if the equipartition law were obeyed there ought, corresponding to these five stars of periods between 30 and 1000 years, to be also, within five parsecs of the Sun, thousands of binaries with periods between 30 days and 30 years, and millions with periods less than 30 days. This being impossible, it seems likely that there is a real excess of stars of periods between 30 and 1000 years. The average effect of recent encounters on these periods, if any, would of course have been in the direction of shortening, so that the excess, if real, would point to an origin in which the period was something greater than at present.

This result, although based on somewhat uncertain evidence, seems to demand a reversal of the conclusion reached in my previous paper. It was there assumed, on the basis of Russell's investigation "On the Origin of Binary Stars," † that binaries had necessarily originated by fission, the reason being the observed arrangement of triple systems in close and wide pairs. On further consideration, this assumption seems to be unwarranted. Russell's investigation proved that if a system had originated by fission it would show the observed arrangement, but the argument is not reversible; Russell did not prove that no other origin could result in close and wide pairs.

Imagine two adjacent condensations in a nebula failing to get gravitationally clear of one another and describing elliptic orbits about one another. After a time the periods of rotation and revolution will approximately coincide. As soon as this happens, the system becomes dynamically indistinguishable from one which has originated by fission. It is at this stage that Russell's dynamical investigation begins, so that his results apply both to binaries which have originated from independent nuclei and to binaries which have formed by fission. Provided only that the close pair in a triple system is formed by fission, such systems will show the characteristic spacing on which Russell's argument is based, independently of whether the wide pair have originated by fission or as independent nuclei.

Thus, so far as Russell's argument goes, we are still free to imagine that long-period binaries are the relics of independent adjacent condensations. On this hypothesis the close packing which is necessary to provide encounters of sufficient frequency and force is provided, automatically and without any further hypothesis, as a consequence of the contiguity of adjacent condensations: the condensations are initially almost touching. Not only this, but the necessity for close encounters has disappeared;

* *Stellar Movements*, p. 41.
† *Ap. J.*, 31 (1910), p. 185.

we are now free to imagine the periods of these binaries to have been always about equal to their present values. An initial period of 100 years would correspond to a mean density for the nebular condensations of the order 10^{-11}, which is neither impossible nor unreasonable. Finally, the hypothesis of origin from independent condensations provides of itself a resisting atmosphere in which the orbital motion would at first take place: this would result in a lowering of all eccentricities and in an elimination of eccentricities approximating to unity.

No conclusion is announced in the present paper; the available evidence as to the distribution of binaries hardly seems to warrant a definite conclusion. In any case, the mathematician may claim that his task is finished when he has provided the theoretical results against which the practical astronomer can measure his observations.

The Spectra of Nova Aquilæ No. 3. I. *The Dark-Line Spectrum.*

By Joseph Lunt, D.Sc., F.I.C. (Plates 5, 6.)

(*Communicated by S. S. Hough, M.A., F.R.S., H.M. Astronomer at the Cape.*)

The discovery of this nova was announced in a telegram from Mr. R. Watson of Beaufort West* sent to H.M. Astronomer late on the night of 1918 June 8.

On discovery the nova was seen as a second magnitude star between 7h. 50m. and 7h. 55m. G.M.T.—whilst the sun was still shining in England,—and this observation therefore preceded the many observations communicated to the Astronomer Royal on that date. As the night of the 8th was cloudy at Cape Town, the star was not observed until the night of the 9th, when it had become a brilliant white star of estimated magnitude 0·1–0·2. On the 9th, whilst still too low for observations with the slit spectroscope, it was observed between heavy clouds, and a small-scale objective-prism photograph was secured before the sky became overcast and no further work was possible.

As seen in the focus of the object-glass prism camera, the spectrum appeared to be devoid of bright lines. A trailed photograph taken on an ordinary photographic plate showed no bright lines. The absorption lines of hydrogen and calcium H_β, H_γ, H_δ, H_ϵ, and K were strong. The following cablegram was despatched next morning (June 10) from H.M. Astronomer to the Astronomer Royal:—

> "Spectrum Nova contains dark hydrogen and calcium lines similar to Nova Persei 1901 Feb. 22."

As photographs with better apparatus were obtained elsewhere about this time, the above photograph will receive no further

* *Cape Astronomical Association Circular*, No. 2.

attention. Photographs taken at Johannesburg (kindly sent by Mr. Innes, the Union Astronomer) and at Ottawa (reproduced in *J.R.A.S.C.*, 12, 268) show that the doubling of the strong hydrogen lines and other lines—which is so marked a feature of later photographs—had not then taken place.

The nights of June 10, 11, and 12 were clear, and on each night a number of photographs were secured with the four-prism slit spectrograph and short camera attached to the 24-inch Victoria telescope, an iron spark comparison spectrum being impressed on each plate. Messrs. Woodgate and Baines assisted by exposing the plates, which were immediately developed, and the exposures of the later plates were adjusted in accordance with the indications given by the earlier plates. For future work I consider this procedure to be essential to the extraction of the fullest information from spectra of Novæ at this stage, as the photographic effect is so unequal in different parts of the spectrum that a series of photographs with graduated exposures is necessary to obtain the best results for the different regions. This is all the more necessary as the displacements of the lines were evidently undergoing rapid changes, as shown by Harper's measures and also by the Cape photographs.

As the photographs obtained on the above three nights mark a definite stage in the history of the nova, which had ended when further photographs were secured on the 15th,* the present paper deals only with them. The profound changes which took place in the spectrum from June 15 onwards are reserved for discussion in subsequent communications. In the present paper particular attention is paid to the chemical composition of the vapours producing the absorption spectrum, and to the displacement of the lines, which I regard as a true Doppler effect representing real velocities in the line of sight.

This is the first occasion on which the dark-line spectrum of a nova has been recorded with so much detail which could be satisfactorily analysed, and marks an epoch in the history of these bodies which is the beginning of a new stage of our knowledge of them. The favourable position of the nova is exceedingly fortunate, as it has been possible to observe it continuously for many months from both hemispheres before losing it in the evening twilight, and the great advance in the provision of spectographic equipment at observatories in different parts of the world since Anderson's bright nova in Perseus, should yield a rich harvest of results.

Incidentally, the analysis of the spectra here considered has thrown a new light on the spectrum of Nova Geminorum No. 2, which is shown in a previous communication † to have many dark lines in common with the present nova.

* Harper's plates on the 13th and 14th appear to show that the change was then in progress, *J.R.A.S.C.*, 12, 269.

† *M.N.*, 79, 130–136. Adams and Joy (*J. Ast. Soc. Pac.*, 30, 306) confirm the work here quoted.

The photographs extend from the titanium line at λ 3900·7 to the enhanced iron line (?) at λ 5169·1. They are in good focus over a portion only of this range, *i.e.* between λ 4120 and λ 4550. This is sufficient for the radial velocity work usually carried out with the instrument. The region further to the ultra-violet gradually becomes out of focus, and the region further to the red much more abruptly, but in spite of this the spectra are quite serviceable over the longer range. The wave-lengths in the ultra-violet portion are probably not much affected, but the wave-lengths beyond the chromium line at λ 4824·3 are not much relied on, as at this point the colour curve becomes steep and the iron comparison lines are scarce and badly winged. There is uncertainty therefore in the wave-lengths of the pairs of lines attributed to enhanced iron at λλ 4924·1, 5018·6, and 5169·1, and it is uncertain how far the two former are blended with the helium lines at 4922·1 and 5015·7. It is hoped that other instruments will have this region in focus, and for future work it is desirable to have means of rapidly placing this important region central on the plate and in the best possible focus, and with sufficient dispersion to clear up the uncertainties as to the origins of these lines. The measures indicate that the two former lines are principally due to enhanced iron, whereas they have often been assumed to be due principally to helium.

The scale of the plates is as under, measuring towards the red in each case:—

		λ per mm.	·01R =1 Div. on Micr. =			λ per mm.	·01 R =1 Div. on Micr. =
At	λ3900	λ10·34	λ0·05	At	λ4500	λ23·27	λ0·12
	4000	12·14	·06		4600	25·89	·13
	4100	14·07	·07		4700	28·69	·14
	4200	16·16	·08		4800	31·63	·16
	4300	18·40	·09		4900	34·73	·17
	4400	20·77	·10		5000	36·79	·18

Whilst the star was still bright it was possible to obtain much broader spectra than usual, and this is of advantage in a spectrum where the lines are often ill-defined and broad. The "windows" covering the slit are shaped as in figs. 1 and 2.

Usually, for radial velocity work, the starlight is admitted only through the central portion of the slit (*b*, fig. 1), but in the spectra reproduced the star image was trailed to and fro along the slit by means of the slow motion, over the lengths of slit exposed, marked *a*, *b*, and *c*.

The advantage of this will be apparent from the plates showing reproductions of the spectra. Lines which are perfectly apparent in the broad spectrum would in many cases become very uncertain were the two broad outer strips absent.

The light from the iron spark is admitted to the portions of

slit marked *a'* and *c'* in fig. 2, the "window" of fig. 2 replacing that of fig. 1, over the centre of the slit.

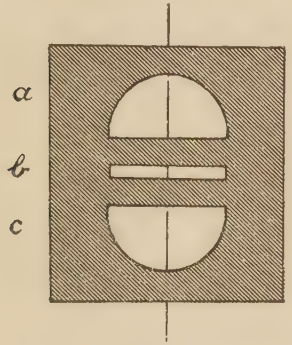


FIG. 1.

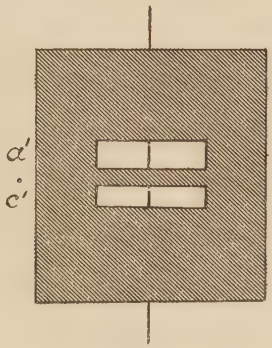


FIG. 2.

The two black bands running the length of the star spectrum are caused by the two bars shown in fig. 1.

The following plates were exposed:—

Date.	Plate No.	Sid. Time.	G.M.T.	Expr.	Defn.	Exposed by	Region of Slit.
1918		h m	h m	m			
June 10	5255	17 39·5	11 11	4	1–2	JL & AB	*a, b & c.*
	5256	18 1·0	11 33	14	,,	,,	*a, b & c.*
	5257	18 24·5	11 57	2	,,	,,	*b* only.
	5260	19 49·0	13 21	40	,,	,,	*a, b & c.*
	5261	20 57·0	14 29	32	,,	,,	*a, b & c* (hazy).
11	5265	16 33·0	10 1	40	,,	RW	*a, b & c.*
	5266	17 39·0	11 7	65	,,	,,	*a, b & c*
	5267	18 35·5	12 4	16	,,	,,	*a, b & c.*
12	5268	16 43·0	10 7	20	,,	AB	*a, b & c.*
	5269	17 42·0	11 6	60	,,	AB	*a, b & c.*

Plate 5266 and the central portion of plate 5269 are enlarged and sent for reproduction with the origins of the lines marked.

The plates taken on June 10 give spectra which show the lines fairly well defined on the violet side, but the lines are broad and fade off gradually towards the red. For the identification of the lines they are much inferior to those taken on the two following days, which show a progressive improvement as regards sharpness. On the 10th the absorbing atmosphere of the star was evidently in a very disturbed state, and large variations of velocity in different parts of it probably account for the diffuse nature of the lines. The wings to the lines on the red side seen on the 10th would appear to be due to vapours torn from the parent body

decreasing in velocity as they are left behind, as the better-defined lines on the two following days correspond in displacement to that of the better-defined violet edges of the lines on the earlier plates.

For the analysis of the lines as regards chemical composition of the absorbing vapours, therefore, the plates 5266 and 5269 are alone considered.

The nights of June 13 and 14 were cloudy, and on the night of the 15th the complex spectrum of the 10th, 11th, and 12th had vanished and a much simpler spectrum remained.

The measures were made on a Toepfer measuring microscope with a screw of half-millimetre pitch. Single settings on the iron comparison lines and on the star lines were made in all cases except the measures in Table VII., in which case the settings were repeated in the reverse order and the duplicate settings repeated with the plate reversed.

The agreement between these measures and the rest indicated that single settings were sufficiently accurate for the identifications, considering the few elements involved.

The titanium spectrum is of particular interest, as it consists entirely of enhanced lines, thirty-eight of which are present—a condition which cannot be produced in the laboratory,—and an indication of an excessively high temperature. None of these lines are doubled, as are some of the enhanced iron lines in common with those of hydrogen and the H and K lines of calcium. These two latter also occur as fine sharp dark lines which are near their normal positions, as has been the case in previous novæ. These fine lines are regarded as evidence of a tenuous nebula in the neighbourhood of the nova but not partaking of its motion.* The nebula is shown by the measures to be almost stationary with respect to our stellar system, and it may be intimately involved in the outburst of the nova. The nova itself is regarded as moving with the velocity indicated by the displacements of the metallic lines, viz. radial velocities -1495 km./s. and -1530 km./s. on June 11 and 12 respectively, and no other explanation of the shift in the spectrum has so far appeared or suggested itself. The difficulty of accepting these shifts as true Doppler effects disappears if, as I have ventured to suggest in a letter to *Nature* (102, 194), we regard the nova as a stranger to our system entering it from outside. The proper motion of our system is quite unknown, but it is reasonable to suppose that it is comparable with the radial velocities found for spiral nebulæ—which some regard as replicas of our system,—which in the case of N.G.C. 1068 amounts to $+1120$ km. per

* As pointed out by Kobold (*A.N.*, 207, 4955, p. 130), the star is shown on plate viii. of Barnard's photograph of the Milky Way in Scheiner's Atlas in *Die photographie der Gestirne*, 64·3 mm. from the left border and 19·6 mm. from the top border of the photograph, taken 1892 June 24, exposure 3h. 25m. It appears on the confines of a rich nebulous region. [The bright star almost central is 6 Aquilæ, and the brighter one showing halation (on the left border) is 15 Aquilæ.]

second, according to Dr. Slipher.* If we accept this velocity for the spiral nebulæ, there seems no reason why we should not accept a velocity of −1500 for Nova Aquilæ as the combined motion of our system and the star.

Between the strontium line 4215·7 and the calcium line 4226·9 is a stronger line which must be regarded as of unknown origin if it belongs to the same set as regards displacement, but if we regard it as belonging to the duplicate set of lines shown by hydrogen, enhanced iron, and the H and K lines of calcium, it is a companion to the enhanced iron line 4233·3—the strong line following the calcium line 4226·9,—with a displacement corresponding to the violet component of the other double lines.

According to this view, which is more probably correct, besides the hydrogen lines H and K of calcium, the following enhanced iron lines are doubled, viz.:—

4233·3 4924·1 5018·6 5169·1 (?)

The mean difference of velocity displacement between the more refrangible lines of the pairs from K to H_β and the mean of the metallic lines is 702 km./s. on June 11 and 676 km./s. (omitting H_β) on June 12. These correspond to a displacement in λ at H_γ of λ10·6 and λ9·79 respectively. The velocity displacements between the two lines of the doubles in Nova Geminorum No. 2, given by the measures of Adams and Kohlschutter, are very discordant among themselves, but they suggest that the velocity separations may be the same for the two novæ. It therefore seems improbable that the extra lines are due to a separate mass of absorbing vapour, and they may be an effect of the excessively high temperature of the novæ.

In the absence of any satisfactory explanation of them, we can only record the facts.

Table VIII. gives the mean measured wave-lengths and origins of the lines, corrected for displacement, as compared with Rowland's wave-lengths of the solar lines. The great majority of the lines are satisfactorily accounted for, but a few lines remain for which no origin has been found. The following elements have been recognised:—Ti, Fe, Cr, Sc, Sr, Ca, Mg, H, He. Vanadium may be present, but the evidence is weak.

The two enlargements accompanying the paper show the spectra of June 11 and 12.

In Plates 5 and 6 the extraordinary displacement of the strong iron lines is indicated by the oblique lines connecting the iron lines of the comparison spectrum (bright lines) with the corresponding dark lines displaced to the violet in the Nova.

Strips 1 and 3 of Plate 5 are printed with different exposures from the same negative. Strips 3, 4, and 5 are similarly treated, to show pairs of lines where the intensity of the continuous spectrum falls off rapidly at the red end.

The bright H_β is well shown. The three K lines K_0, K_1, and

* *J.R.A.S.C.*, 12, 190, 241.

K_2 in strip 1 show the displacements strikingly, K_0 being near its normal position. In Plate 6 the line $H\delta^2$ is sharp on the violet side and diffuse on the red side, whereas next day the reverse is the case. The increased shift of $H\delta^1$ on June 12 is well shown. The broad lines indicate large disturbances of the hydrogen and calcium atmospheres which are not shown by the more quiescent metallic vapours, the lines of which are comparatively narrow and sharp.

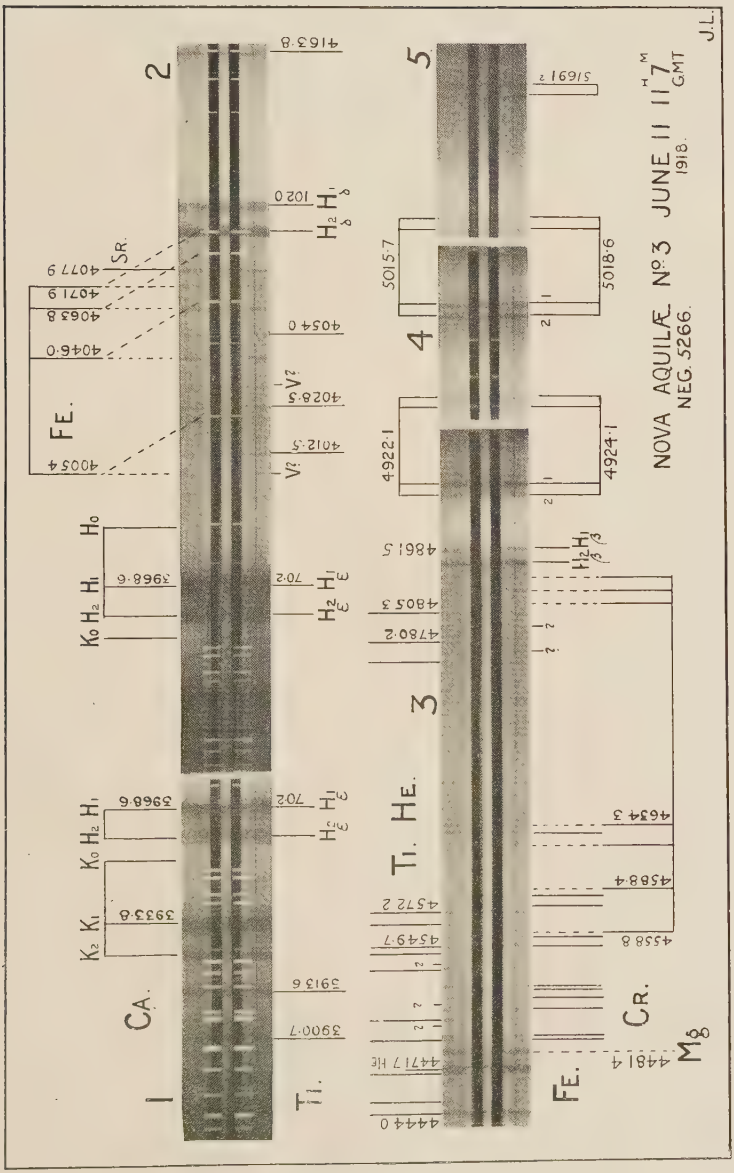
The very broad bright bands of hydrogen at $H\delta$ and H^γ are shown in Plate 6, but it is impossible to define their ending on the red side, as they gradually merge into the continuous spectrum. It is clear, however, that they extend much beyond their normal positions towards the red. It is probable that powerful repulsive forces emanate from the highly incandescent star, such as cause comets' tails to be repelled from the sun, and these would have their maximum effect on hydrogen, which would form an expanding envelope of particles having radial velocities zero when moving across the line of sight. If the envelope is torn from the parent body by a resisting medium, the portions left behind might acquire a receding radial velocity owing to this repulsive force.

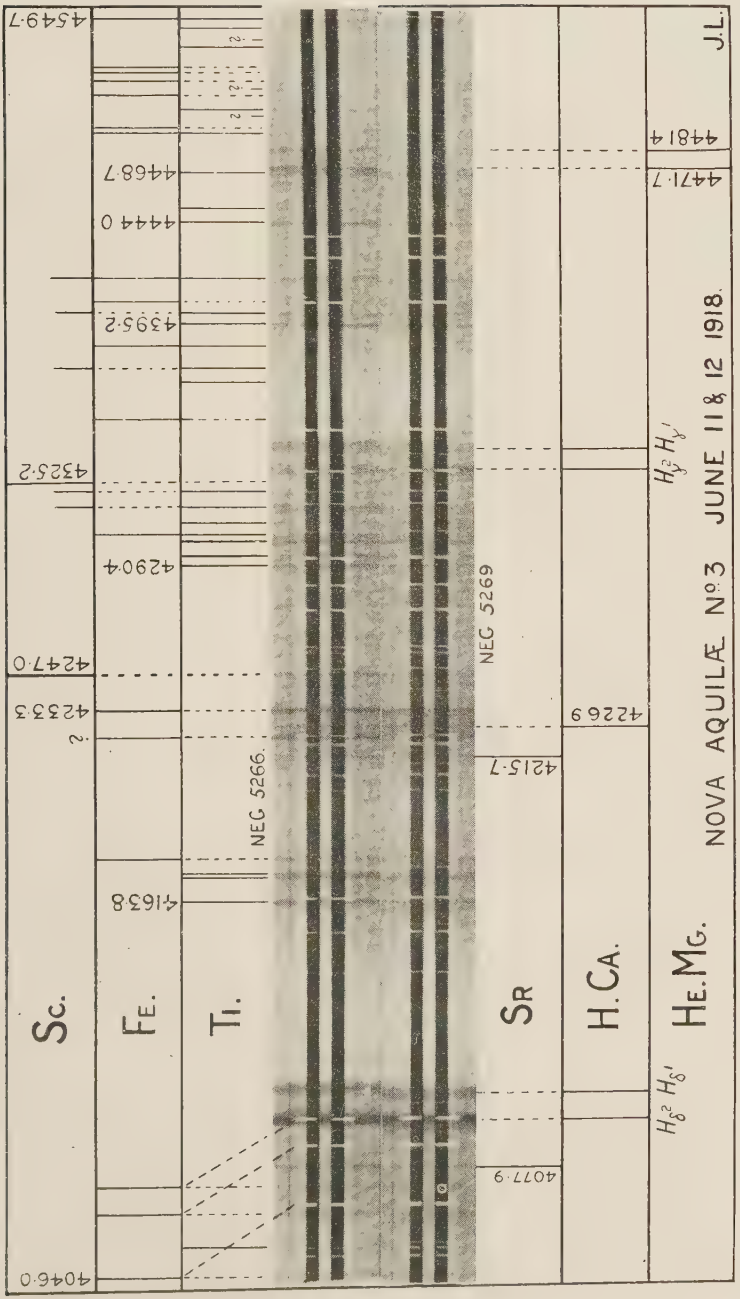
The broad bright bands on these suppositions are Doppler effects, the luminous gases causing them showing a very wide range of radial motion in different parts of the mass of gas given off by the high-velocity star during its passage through a resisting medium. In this connection the views of Evershed and Campbell may be noticed (vide *L.O.B.*, 8, 82). The latter states that the wide hazy absorption lines in many spectra of early types could find simple explanation as Doppler effects. In novæ the phenomena are more complicated, as we have to deal in all probability with three bodies: (1) the star proper; (2) an absorbing resisting medium, evidenced by the sharp H, K, and D lines; (3) the gaseous products of the outburst produced by the interaction of (1) and (2).

The later spectra of the nova are probably due almost entirely to the third body, and they will form the subject of further communications.

Tables I. to VIII. give the measures of the spectra.

Royal Observatory,
Cape of Good Hope:
1918 *Dec.* 27.


NOVA AQUILÆ No. 3 JUNE 11 11H 7M G.M.T. 1918.
NEG. 5266.
J.L.
1
2
3
4
5
CA.
Ti.
Ti. He.
Fe.
Cr.
Mδ
SR.
V?
V?
K2 K1
K0 H2 H1
H2 H1 ε
H2 H1 δ
H0
3933.6
3968.6
3900.7
4163.8
4077.9
4071.9
4063.8
4046.0
4005.4
4028.5
4012.5
4054.0
4102.0
4922.1
4924.1
5015.7
5018.6
5169.2
4444.0
4471.7 He
4572.2
4549.7
4780.2
4805.3
4861.5
4558.8
4588.4
4634.3
4481.4


NOVA AQUILÆ No 3 JUNE 11 & 12 1918.
J.L.
Sc.
Fe.
Ti.
Sr
H. Ca.
He. Mg.
NEG 5266.
NEG 5269
4549·7
4468·7
4444·0
4395·2
4325·2
4290·4
4247·0
4233·3
4163·8
4046·0
4077·9
4215·7
4226·9
4471·7
4481·4
H_δ^2 H_δ'
H_γ^2 H_γ'

The Measures.

TABLE I.

Plate 5266, 1918 June 11. Bk. x. pp. 29–31.

Standard iron lines, 3856·524, 4030·646, 4236·112.

	Measured λ in Nova.	Origin.	Rowland's λ in ⊙.	Shift in λ.	Factor km./s. per λ.	Shift in km./s.	Correction for −1504 km. Shift.	Corrected Observed λ.	Observed minus Tabular λ.
	3881·10	Ti_E	3900·68	−19·58	76·87	−1505	+19·57	3900·67	−·01
	3894·44	Ti_E	3913·61	19·17	76·62	1469	19·63	3914·07	+·46
K_2	3905·04	Ca	3933·83	28·79	76·23	(2195)			
K_1	3913·44	,,	,,	20·39	,,	1554	19·73	3933·17	−·66
K_0	3933·47	,,	,,	−0·36	,,	(−27·4)			
H_2	3940·35	$H_\epsilon Ca$	3969·40	29·05	75·54	(2194)			
H_1	3949·21	,,	,,	20·19	,,	1525	19·91	3969·12	−·28
	3950·05 *	H_ϵ	3970·18	20·13	75·53	1520	19·91	3969·96	−·22
H_0	3968·33	Ca	3968·63	−0·30	75·56	(−22·7)			
	3985·69	Fe	4005·41	19·72	74·86	1476	20·09	4005·78	+·37
	3992·31	Ti_E	4012·54	20·23	74·73	1512	20·13	4012·44	−·10
	4008·57	Ti_E	4028·50	19·93	74·43	1483	20·20	4028·77	+·57
	4025·40	Fe	4045·98	20·58	74·11	1525	20·29	4045·69	−·29
	4033·95	Ti_E	4053·98	20·03	73·97	1482	20·33	4054·28	+·30
	4043·14	Fe	4063·76	20·64	73·79	1523	20·38	4063·52	−·24
	4051·62	Fe	4071·91	20·29	73·64	1494	20·42	4072·03	+·12
	4057·22	Sr_E	4077·89	20·67	73·53	1520	20·45	4077·67	−·22
$H\delta^2$	4072·12	$H\delta$	4102·00	29·88	73·10	(2184)			
$H\delta^1$	4081·63	,,	,,	20·37	,,	1489	20·57	4102·20	+·20
	4143·20	Ti_E	4163·82	20·62	72·02	1485	20·88	4164·10	+·28
	4151·40	Ti_E	4172·07	20·67	71·87	1486	20·93	4172·33	+·26
	4152·96	Ti_E(du)	4173·98	21·02	71·84	1510	20·94	4173·90	−·08
	4158·26	Fe_E	4179·03	20·77	71·75	1490	20·96	4179·22	+·19
	4194·45	Sr_E	4215·70	21·25	71·13	1512	21·14	4215·59	−·11
Fe_E^2	4201·80	? Fe_E^2	4233·33	31·53	70·83	(2233)			
	4205·50	Ca	4226·90	21·40	70·94	1518	21·20	4226·70	−·20
Fe_E^1	4211·92	Fe_E^1	4233·33	21·41	70·83	1516	21·23	4233·15	−·18
	4225·61	Sc	4247·00	21·39	70·61	1510	21·30	4246·91	−·09

	Second Set.	First Set.	Zero Set.
Mean shift . .	−2202 (4 lines)	−1504 (22 lines)	−25·0 (2 lines)

* Max. E = Enhanced.

TABLE II.

Plate 5266, 1918 June 11. Bk. x. pp. 36–38.

Standard iron lines, 4185·06, 4376·11, 4584·02.

Measured λ in Nova.	Origin.	Rowland's λ in ⊙.	Shift in λ.	Factor km./s. per λ.	Shift in km./s.	Correction for −1506 km. Shift.	Corrected Observed λ.	Observed minus Tabular λ.
4194·39	Sr_E	4215·70	−21·31	71·13	−1516	+21·17	4215·56	−·14
Fe_E^2 4201·87	? Fe_E^2	4233·33	31·46	70·83	(2228)			
4205·64	Ca	4226·90	21·26	70·94	1508	21·23	4226·87	−·03
Fe_E^1 4211·81	Fe_E^1	4233·33	21·52	70·83	1524	21·26	4233·07	−·26
4225·47	Sc	4247·00	21·53	70·61	1520	21·33	4246·80	−·20
4268·57	Ti_E	4290·38	21·81	69·89	1524	21·55	4290·12	−·26
4272·69	Ti_E	4294·20	21·51	69·83	1502	21·57	4294·26	+·06
4278·47	Ti_E	4300·21	21·74	69·73	1520	21·60	4300·07	−·14
4281·08	$Ti_E Fe_E Ca$	4302·39	21·31	69·70	1485	21·61	4302·69	+·30
4286·32	$Ti_E Fe$	4308·08	21·76	69·60	1514	21·64	4307·96	−·12
4292·48	(du)$Ti_E Sc$	4314·09	21·61	69·51	(1502)	21·67	4314·15	+·06
4299·22	$ScTi_E$	(4321·01)	21·79	69·40	1512	21·70	4320·92	−·09
4303·76	Sc / Fe	4325·15 / 4325·94	21·79	69·32	1510	21·73	4325·49	−·06
$H\gamma^2$ 4308·97	$H\gamma$	4340·63	31·66	69·08	(2187)			
$H\gamma^1$ 4318·55	,,	,,	22·08	,,	(1525)	21·80	4340·35	−·28
4322·89	Ti_E	4344·45	21·56	69·02	(1488)	21·82	4344·71	+·26
4330·20	Fe_E	4351·93	21·73	68·90	1497	21·86	4352·06	+·13
4337·01	Fe	4358·67	21·66	68·80	(1490)	21·89	4358·90	+·23
4346·55	Ti_E	4367·84	21·29	68·65	(1462)	21·94	4368·49	+·65
4352·94	Sc / Ti_E	4374·63 / 4375·10	21·93	68·54	1503	21·97	4374·91	+·04
* 4361·15 / Band / 4365·21	Fe / Fe_E / Ti_E	4383·72 / 4385·55 / 4387·01	...	...	...	...	4383·23 / Band / 4387·29	
4373·10	Ti_E	4395·20	22·10	68·22	1508	22·08	4395·18	−·02
4378·22	Ti_E / Sc	4399·94 / 4400·56	22·01	68·15	1500	22·10	4400·32	+·07
4383·15	Fe	4404·93	21·78	68·07	(1483)	22·12	4405·27	+·34
Bd 4392·50 / 4396·60	Fe, Sc / Ti_E	4415·50 / 4417·88	22·14	67·89	(1503)	22·18	4416·73	+·04
4421·86	Ti_E	4443·98	22·12	67·84	1493	22·20	4444·06	+·08
4428·42	Ti_E	4450·65	22·23	67·37	1498	22·35	4450·77	+·12

* Vanadium line 4384·87 possibly involved.

TABLE II.—*continued.*

Measured λ in Nova.	Origin.	Rowland's λ in ⊙.	Shift in λ.	Factor km./s. per λ.	Shift in km./s.	Correction for −1506 km. Shift.	Corrected Observed λ.	Observed minus Tabular λ.
f Bd 4438·36	Fe_E	4462·17	−22·72	67·18	−1526	+22·42	4463·10	−·30
4443·00	Ti_E	4464·62						
4446·18	Ti_E	4468·66	22·48	67·10	1508	22·44	4468·62	−·04
4448·47	He	4471·65	23·18	67·06	(1554)	22·46	4470·93	−·72
4459·17	Mg	(4481·40)	22·23	66·91	1487	22·51	4481·68	+·28
4466·57	Ti_E	4488·49	22·35	66·80	1493	22·54	4489·11	+·19
	Fe_E	4489·35						
4468·98	Fe_E	4491·57	22·59	66·76	1508	22·56	4491·54	−·03
4474·92	?	...	...	...	...	22·59	4497·51	
4478·91	Ti_E	4501·45	22·54	66·61	1501	22·61	4501·52	+·07
4486·02	Fe_E	4508·46	22·44	66·51	1490	22·64	4508·66	+·20
4489·37	?	...	...	...	...	22·66	4512·03	
4492·40	Fe_E	(4515·51)	23·11	66·40	1535	22·68	4515·08	−·43
du 4497·21	Fe_E	4520·40	23·19	66·33	1538	22·70	4519·91	−·49
4499·87	Fe_E	(4522·80)	22·93	66·30	1520	22·71	4522·58	−·22
4511·54	Ti_E	4434·14	22·60	66·13	1495	22·77	4534·31	+·17
4516·15	? Fe(du)	4538·97	22·82	66·06	1507	22·80	4538·95	−·02
4521·66	Ti_E	4544·19	22·53	65·99	(1487)	22·82	4544·48	+·29
4527·13	Fe_ETi_E	4549·73	22·60	65·91	1490	22·85	4549·98	+·25
4533·30	Fe_E	4556·06	22·76	65·82	1498	22·88	4556·18	+·12
4535·66	Cr_E	4558·83	23·17	65·78	1524	22·89	4558·55	−·28
4541·07	Ti_E	4563·94	22·87	65·70	1503	22·92	4563·99	+·05
4549·44	Ti_E	4572·16	22·72	65·58	1490	22·96	4572·40	+·24
4553·39	Fe_E	4576·51	23·12	65·52	(1515)	22·99	4576·38	−·13
4561·07	Fe_E	4584·02	22·95	65·41	1501	23·02	4584·09	+·07

	Second Set.	First Set.
Mean shift . . .	−2208 (2 lines)	−1506 (45 lines)

Note.—The bracketed shifts in km./s. belong to the more diffuse lines. Excluding them does not affect the mean appreciably.

TABLE III.

Plate 5266, 1918 June 11. Bk. x. pp. 33–34.

Standard iron lines, 4528·80, 4736·96, 5018·63.

Measured λ in Nova.	Origin.	Rowland's λ in ☉.	Shift in λ.	Factor km./s. per λ.	Shift in km./s.	Correction for −1504 km. Shift.	Corrected Observed λ.	Observed minus Tabular λ.
4533·41	Fe_E	4556·06	−22·65	65·82	−1491	+22·85	4556·26	+·20
4535·79	Cr_E	4558·83	23·04	65·78	1516	22·86	4558·65	−·18
4541·15	Ti_E	4563·94	22·79	65·70	1497	22·89	4564·04	+·10
4549·82	Ti_E	4572·16	22·34	65·58	1465	22·93	4572·75	+·59
4560·97	Fe_E	4584·02	23·05	65·41	1508	22·99	4583·96	−·06
4565·11	Cr_E	4588·38	23·27	65·35	1521	23·01	4588·12	−·26
4596·15	Cr_E	4618·97	22·82	64·92	1481	23·17	4619·32	+·35
4606·00	Fe_E	4629·52	23·52	64·77	1523	23·22	4629·22	−·30
4611·00	Cr_E	4634·25	23·25	64·71	1505	23·24	4634·24	−·01
4707·95	?					23·49	4731·44	
4739·66	Ti_E	4764·11	24·45	62·94	1539	23·89	4763·55	−·56
4747·04	?					23·93	4770·97	
4756·43	Ti_E	4780·17	23·74	62·73	1489	23·98	4780·41	+·24
4769·93	?					24·05	4793·98	
4780·43	Ti_E	4805·29	24·86	62·40	1551	24·10	4804·53	−·76
4788·82	Cr_E	(4812·72)	23·90	62·31	1489	24·14	4812·96	+·24
4800·28	Cr_E	4824·33	24·05	62·16	1495	24·20	4824·47	+·14
4812·35	Cr_E	4836·40	24·05	62·00	1491	24·26	4836·61	+·21

Mean shift 15 lines −1504.

Beyond this point, towards the red, the focus falls off rapidly and the wave-lengths are not regarded as sufficiently accurate for the determination of radial velocities.

There are four important pairs of lines shown on the photographs. The measures of three of these corrected for the shifts −2204 and −1505 found from the preceding lines are as under—

Origin.	Corrected Measured λ.	Mean Observed λ.	Tabular λ.	Observed minus Tabular λ.
$H\beta^2$	4861·2	4862·2	4861·5	+0·7
$H\beta^1$	4863·3			
$Fe_E{}^2$	4924·5	4924·1	4924·1	0·0
$Fe_E{}^1$	4923·7			
$Fe_E{}^2$	5019·6	5019·4	5018·6	+0·8
$Fe_E{}^1$	5019·1			

The measures indicate that the two latter pairs are due entirely to enhanced iron, and the presence of a par-helium component is regarded as very doubtful.

Photographs with other instruments may settle this point.

The fourth pair is beyond the comparison lines, and is probably due to the enhanced iron line at 5169·1 and not to magnesium.

Radial Velocities. June 11.

3856–4236	−1504 (22 lines)	−2202 (4 lines)	−25·0 (2 lines)
4185–4584	−1506 (45 ,,)	−2208 (2 ,,)	
4529–5019	−1504 (15 ,,)		
Weighted mean shift	−1505	−2204	−25·0
Correction to sun	+ 10·4	+ 10·4	+10·4
Radial velocity	−1494·6	−2193·6	−14·6
Solar motion corrn.	+ 17·1	+ 17·1	+17·1
Corrected rad. vel.	−1477·5 km./s.	−2176·5 km./s.	+ 2·5 km./s.

TABLE IV.

Plate 5269, 1918 June 12. Bk. x. p. 21.
Standard iron lines, 3920·41, 4132·24, 4415·29.

Measured λ in Nova.		Origin.	Rowland's λ in ⊙.	Shift in λ.	Factor km./s. per λ.	Shift in km./s.	Correction for −1545 km. Shift.	Corrected Observed λ.	Observed minus Tabular λ.
K_0	3933·62	Ca	3933·83	− 0·21	76·23	−(16·0)			
H_ϵ^2	3939·36	H, Ca	3969·40	30·04	75·54	(2269)			
	3940·52	H	3970·18	29·66	75·53	(2240)			
H_ϵ^1	3947·91	H, Ca	3969·40	21·49	75·54	(1623)			
	3949·48	H	3970·18	20·70	75·53	(1563)			
H_ϵ^0	3968·34	Ca	3968·63	0·29	75·56	(21·9)			
	4025·08	Fe	4045·98	20·90	74·11	1549	+20·85	4045·93	−·05
	4032·99	Ti_E	4053·98	20·99	73·97	1553	20·89	4053·88	−·10
	4057·18	Sr_E	4077·89	20·71	73·53	1523	21·01	4078·19	+·30
$H\delta^2$	4071·70	$H\delta^2$	4102·00	30·30	73·10	(2215)			
$H\delta^1$	4079·32	$H\delta^1$	4102·00	22·68	73·10	(1658)			
	4142·45	Ti_E	4163·82	21·37	72·02	1539	21·45	4163·90	+·08
	4150·55	Ti_E	4172·07	21·52	71·87	1547	21·50	4172·05	−·02
	4152·15	Ti_E(du)	4173·98	21·83	71·84	1568	21·51	4173·66	−·32
	4157·23	Fe_E	4179·03	21·80	71·75	1564	21·53	4178·76	−·27
	4194·29	Sr_E	4215·70	21·41	71·13	1523	21·72	4216·01	+·31
Fe_E^2	4202·05	Fe_E^2	4233·33	31·28	70·83	(2216)			
	4205·34	Ca	4226·90	21·56	70·94	1529	21·78	4227·12	+·22
Fe_E^1	4211 10	Fe_E^1	4233·33	22·23	70·83	1575	21·81	4232·91	−·42
	4225·19	Sc	4247·00	21·81	70·61	1540	21·88	4247·07	+·07
	4268·20	Ti_E	4290·38	22·18	69·89	1550	22·11	4290·31	−·07
	4272·10	Ti_E	4294·20	22·10	69·83	1543	22·13	4294·23	+·03
	4277·90	Ti_E	4300·21	22·31	69·73	1556	22·16	4300·06	−·15
	4372·52	Ti_E	4395·20	22·68	68·20	1547	22·65	4395·17	−·03
	4421·36	Ti_E	4443·98	22·62	67·84	1535	22·77	4444·13	+·15

	Second Set.	First Set.	Zero Set.
Mean shift . .	−2235 (4 lines)	−1545 (16 lines)	−19·0 (2 lines)

Notes.—The two wave-lengths for H_ϵ^2 and H_ϵ^1 are for the middle and the maxima of the lines respectively.

$H\delta$ and H_ϵ are not used for measure of shift.

TABLE V.

Plate 5269, 1918 June 12. Bk. x. pp. 39–40.

Standard iron lines, 3920·41, 4132·24, 4415·29.

Measured λ in Nova.	Origin.	Rowland's λ in ☉.	Shift in λ.	Factor km./s. per λ.	Shift in km./s.	Correction for −1545 km. Shift.	Corrected Observed λ.	Observed minus Tabular λ.
4142·58	Ti_E	4163·82	−21·24	72·02	−1530	+21·45	4164·03	+·21
4150·53	Ti_E	4172·07	21·54	71·87	1548	21·50	4172·03	−·04
Bd 4155·53 / 4157·46	Fe_E	4179·03	...	...	...	21·53 / 21·54	4177·06 / 4179·00	
4194·18	Sr_E	4215·70	21·52	71·13	1531	21·72	4215·90	+·20
Fe_E^2 4202·07	Fe_E^2	4233·33	31·26	70·83	(2214)			
4205·25	Ca	4226·90	21·65	70·94	1536	21·78	4227·03	+·13
Fe_E^1 4211·21	Fe_E^1	4233·33	22·12	70·83	1567	21·81	4233·02	−·31
4225·05	Sc	4247·00	21·95	70·61	1550	21·88	4246·93	−·07
4268·26	Ti_E	4290·38	22·12	69·89	1550	22·11	4290·37	−·01
4272·29	Ti_E	4294·20	21·91	69·83	1530	22·13	4294·42	+·22
4278·03	Ti_E	4300·21	22·18	69·73	1547	22·16	4300·19	−·02
4280·24	$Ti_E Fe_E Ca$	4302·39	22·15	69·70	1544	22·17	4302·41	+·02
4286·09	Ti_E	4308·08	21·99	69·60	1531	22·20	4308·29	+·21
4291·44	Ti_E*Sc	4314·09	22·65	69·51	1574	22·23	4313·67	−·42
4298·65	Ti_ESc	(4321·01)	22·36	69·39	1552	22·27	4320·92	−·09
4302·70	Sc	4325·15	22·45	69·33	1556	22·28	4324·98	−·17
$H\gamma^2$ 4309·07	$H\gamma^2$	4340·63	31·56	69·08	(2180)			
$H\gamma^1$ 4317·31	$H\gamma^1$	,,	23·32	,,	(1611)	22·37	4339·68	−·95
4329·39	Fe_E	4351·93	22·54	68·90	1553	22·42	4351·81	−·12
4345·60	Ti_E	4367·84	22·24	68·65	1527	22·51	4368·11	+·27
4352·50	Sc, Ti_E	4374·87	22·37	68·54	1533	22·54	4375·04	+·17
4360·20 / Band / 4363·80	Fe / Fe_E / Ti_E	4383·72 / 4385·55 / 4387·01		...	...	22·58 / ... / 22·60	4382·78 / Band / 4386·40	
4372·35	Ti_E	4395·20	22·85	68·22	1559	22·65	4395·00	−·20
4377·25	Ti_E	4399·94	22·69	68·15	1546	22·67	4399·92	−·02

	Second Set.	First Set.
Mean shift . . .	−2197 (2 lines)	−1545 (19 lines).

* Double.

TABLE VI.

Plate 5269, 1918 June 12. Bk. x. pp. 25–27.

Standard iron lines, 4299·41, 4584·02, 4957·67 (du).

	Measured λ in Nova.	Origin.	Rowland's λ in ⊙.	Shift in λ.	Factor km./s. per λ.	Shift in km./s.	Correction for −1536 km. Shift.	Corrected Observed λ.	Observed minus Tabular λ.
	4302·55	Sc	4325·15	−22·60	69·33	−1569	+22·15	4324·70	−·55
H_γ^2	4309·00	H_γ^2	4340·63	31·63	69·08	(2185)			
	4308·20 *	,,	,,	32·43	,,	(2240)			
H_γ^1	4317·60	H_γ^1	,,	23·03	,,	(1591)			
	4321·93	Ti_E	4344·45	22·52	69·02	1554	22·25	4344·18	−·27
	4329·62	Fe_E	4351·93	22·31	68·90	1537	22·29	4351·91	−·02
	4345·71	Ti_E	4367·84	22·13	68·65	1519	22·37	4368·08	+·24
	4352·67	Ti_E	4375·10	22·43	68·54	1537	22·41	4375·08	−·02
†	4359·96	Fe	4383·72	...	...	...	22·45	4382·41	
	Band	Fe_E	4385·55	...	...	...	...	Band	
	4363·99	Ti_E	4387·01	...	...	...	22·47	4386·46	
†	4372·38	Ti_E	4395·20	22·82	68·20	1556	22·52	4394·90	−·30
	4377·45	Ti_E	4399·94	22·49	68·15	1533	22·54	4399·99	+·05
	4383·41*	Fe V ?	4404·93 4406·81	22·46	68·06	1529	22·57	4405·98	+·11
diff.	4391·45	FeSc	4415·50	22·74	67·89	1544	22·62	4416·57	−·12
s.	4396·45	Ti_E	4417·88						
	4421·21	Ti_E	4443·98	22·77	67·48	1537	22·76	4443·97	−·01
	4428·09	Ti_E	4450·65	22·56	67·37	1520	22·80	4450·89	+·24
† Bd.	4435·23	Fe_E	4462·17	...	...	...	22·84	4458·07	
	4442·23	Ti_E	4464·62	...	...	...	22·87	4465·10	
	4445·50	Ti_E	4468·66	23·16	67·10	1554	22·89	4468·39	−·27
	4448·86	He	4471·65	22·79	67·06	1528	22·90	4471·76	+·11
	4458·40	Mg	4481·40	23·00	66·91	1539	22·96	4481·36	−·04
	4466·20	$Ti_E Fe_E$	4488·92	22·72	66·80	1518	22·99	4489·19	+·27
	4468·97	Fe_E	4491·57	22·60	66·76	1509	23·01	4491·98	+·41
	4474·91	?	...	...	...	...	23·04	4497·95	
	4478·43	Ti_E	4501·45	23·02	66·61	1533	23·06	4501·49	+·04
	4485·38	Fe_E	4508·46	23·08	66·51	1535	23·08	4508·46	0·00
Bd.	4488·70	?	4515·51	...	...	...	23·10	4511·80	
	4492·71	(Fe_E)					23·12	4515 82	
	4510·79	Ti_E	4534·14	23·35	66·13	1544	23·23	4534·02	−·12
	4516·66	?	...	...	...	...	23·25	4539·91	
	4526·23	$Fe_E Ti_E$	4549·73	23·50	65·91	1549	23·30	4549·53	−·20
	4532·77	Fe_E	4556·06	23·29	65·82	1533	23·34	4556·11	+·05
	4535·77	Cr_E	4558·83	23·06	65·78	1508	23·35	4559·12	+·29
	4540·32	Ti_E	4563·94	23·62	65·70	1552	23·38	4563·70	−·24
	4548·84	Ti_E	4572·16	23·32	65·58	1529	23·42	4572·26	−·10
diff.	4556·30	Fe_E	4584·02	...	...	...	23·47	s. 4583·49	
s.	4560·02								

Mean shift 24 lines −1536 km./s.

* Maximum.

† Vanadium possibly involved.

TABLE VII.

Plate 5269, 1918 June 12. Bk. x. p. 32.

Standard iron lines, 4118·71, 4299·41, 4494·74.

(Ten sharpest lines selected.)

Measured λ in Nova.	Origin.	Rowland's λ in ⊙.	Shift in λ.	Factor km./s. per λ.	Shift in km./s.	Correction for −1535 km. Shift.	Corrected Observed λ.	Observed minus Tabular λ.
4142·57	Ti_E	4163·82	−21·25	72·02	−1530	+21·31	4163·88	+·06
4194·37	Sr_E	4215·70	21·33	71·13	1517	21·58	4215·95	+·25
4225·27	Sc	4247·00	21·73	70·61	1534	21·74	4247·01	+·01
4268·18	Ti_E	4290·38	22·20	69·89	1552	21·96	4290·14	−·24
4272·24	Ti_E	4294·20	21·96	69·83	1533	21·98	4294·22	+·02
4278·07	Ti_E	4300·21	22·14	69·73	1544	22·01	4300·08	−·13
4372·62	Ti_E	4395·20	22·58	68·22	1540	22·50	4395·12	−·08
4421·32	Ti_E	4443·98	22·66	67·48	1529	22·75	4444·07	+·09
4445·66	Ti_E	4468·66	23·00	67·10	1543	22·88	4468·54	−·12
4478·55	Ti_E	4501·45	22·90	66·61	1525	23·04	4501·59	+·14

Mean shift 10 lines −1535 km./s.

Radial Velocities. June 12.

Region.	First Set.	Second Set.	Zero Set.
λ3934 − λ4444 . .	−1545 (16 lines)	−2235 (4 lines)	−19·0 (2 lines)
4164 − 4400 . .	−1545 (19 ,,)	−2197 (2 ,,)	
4325 − 4584 . .	−1536 (24 ,,)	−2213 (1 line)	
4164 − 4501 . .	−1535 (10 ,,)		
Weighted mean shift .	−1540 km./s.	−2221 km./s.	−19·0 km./s.
Correction to sun .	+ 9·9	+ 9·9	+ 9·9
Radial velocity . .	−1530·1	−2211·1	− 9·1
Solar motion corrn. .	+ 17·1	+ 17·1	+17·1
Corrected rad. vel. .	−1513 km./s.	−2194 km./s.	+ 8 km./s.

TABLE VIII.—*The Dark-Line Spectrum of Nova Aquilæ.*

Origin of Line.	Rowland's λ in ⊙.	Nova. June 11. Plate 5266.	Corrected λ. June 12. Plate 5269.	Observed Mean λ (corrected).	Observed minus Tabular λ.	Intensity. in ⊙.	Intensity. Lockyer.*	Intensity. Chromosphere (Dyson). †	Intensity. Nova. June 11.	Remarks.
Ti_R	3900·68	3900·67	...	3900·67	− ·01	5	10	7	v.s.	
Ti_E	13·61	14·07	...	14·07	+ ·46	5	10	7	v.s.	
Ca	33·83	... ‡	... ‡	...	...	1000	...	100	v.s.	K line du.
H_ϵ Ca	68·63	... ‡	... ‡	...	...	700	...	70	v.s.	H ,, ,,
H_ϵ H	70·18	... ‡	... ‡	...	...	5	...	30	v.s.	H ,, ,,
Fe(V_E ?)	4005·41	4005·78	...	4005·78	+ ·37	7	...	2	s.	? V_E involved.
Ti_E	12·54	12·44	...	12·44	− ·10	4	5	10	v.s.	
? Cr_E	12·63				...	0	6–7	...		
Ti_E	28·50	28·77	...	28·77	+ ·27	4	6	2	v.s.	
Fe	45·98	45·69	4045·93	$45·81_2$	− ·17	30	...	3	v.s.	
Ti_E	53·98	54·28	53·88	$54·08_2$	+ ·10	3	5	1	s.	
Fe	63·76	63·52	...	63·52	− ·24	20	...	2	v.s.	
Fe	71·91	72·03	...	72·03	+ ·12	15	...	2	v.s.	
Sr_E	77·89	77·67	78·19	$77·93_2$	+ ·04	8	10	15	v.s.	
Hδ	4102·00	...	...	...	...	40	...	30	v.s.	Hδ line du.
Ti_E	63·82	4164·10	$4163·91_6$	$4163·94_7$	+ ·12	4	10	4	v.s.	
Ti_E	72·07	72·33	$72·04_2$	$72·14_3$	+ ·07	2	10	3	v.s.	

v. = very. w. = weak. s. = strong. diff. = diffuse.

* Tables of wave-lengths of enhanced lines (1906). The intensities of the scandium lines are Exner and Haschek's (spark).

† *Phil. Trans.*, 206, 403–452. ‡ H and K triple. The suffixes after wave-lengths indicate the number of measures.

TABLE VIII.—*continued.*

Origin of Line.	Rowland's λ in ⊙.	Nova. Corrected λ. June 11. Plate 5266.	Nova. Corrected λ. June 12. Plate 5269.	Observed Mean λ (corrected).	Observed minus Tabular λ.	Intensity in ⊙.	Intensity. Lockyer.*	Intensity. Chromosphere (Dyson). †	Intensity. Nova. June 11.	Remarks.
Fe_E	4173·48	4173·90	$4173·63_2$	$4173·72_3$	−·08	2	3	5	v.s.	
Ti_E	73·71					3‡	3	...		
Ti_E	[74·20]					...	2	...		
Fe_E	79·03	79·22	$78·88_2$	$78·99_3$	−·04	3‡	3–4	6	v.s.	
Sr_E	4215·70	$4215·58_2$	$4215·95_6$	$4215·88_8$	+·18	5	10	12	v.s.	
Ca	26·90	$26·79_2$	$27·07_2$	$26·93_4$	+·03	20	...	6	v.s.	
Fe_E	33·33	$33·11_2$	$32·97_2$	$33·04_4$	−·29	4§	4–5	7	v.s.	Fe_E doubled.
Sc_E	47·00	$46·86_2$	$47·01_6$	$46·97_8$	−·03	5	100	10	v.s.	
Ti_E	90·38	90·12	$90·21_6$	$90·20_7$	−·18	2	6	5	v.s.	
Ti_E	94·20	94·26	$94·26_6$	$94·26_7$	+·06	2	7	2	v.s.	
Ti_E	4300·21	4300·07	$4300·10_6$	$4300·10_7$	−·11	3	6	5	v.s.	
Ti_E	02·09	02·69	02·41	$02·55_2$	...	2	3	2	s.	
Fe_E	02·35					2	2–3	1?	diff.	
?Ca	02·69					4	...			
Ti_E	08·08	07·96	08·29	$08·13_2$	+·05	3, 6‖	7	4	s.	
Ti_E	13·03	14·15	13·67	$13·91_2$	...	3	7	2	s.	
Sc	14·25					3	30	2	diff.	
Ti_E	15·14					3	8	3		

Sc Ti_E	20·91 21·12	20·92	20·92	$20·92_2$	...	3 2‡	20 3	4	w. diff.	
Sc	25·15	25·49	$24·84_2$ *	$25·06_3$	−·09	4	20	1	s.	? Fe involved.
H_γ	40·63	...	...	...	...	20	...	100	s.	H_γ line du.
Ti_E	44·45	44·71	44·18	$44·45_2$	0·00	2	3	2	w., diff.	
Fe_E (Cr ?)	51·93	52·06	$51·86_2$	$51·93_3$	0·00	5¶	5	4	w.	
Fe	58·67	58·90	...	58·90	+·23	2	...	...	f.	
Ti_E	67·84	68·49	$68·10_2$	$68·23_3$	+·39	2	5	2	w., diff.	
Sc Ti_E	74·63 74·98	74·91	$75·06_2$	$75·01_3$	... +·03	3 0**	30 3	... ...	w. diff.	
Fe Fe_E Ti_E	83·72 85·55 87·01	Bd 83·23 87·29	$82·60_2$ $86·43_2$	$82·81_3$ $86·72_3$	...	15 2‡ 1	... 3–4 5	5 4 1	w. diff.	
Ti_E	95·20	95·18	$95·06_6$	$95·08_7$	−·12	3	9	8	s.	
Ti_E Sc	99·94 4400·56	4400·32	$99·96_2$	$4400·08_3$	+·14 ...	3 3	7 20	2 3	s.	
Fe V ?	04·93 06·81	05·27	4405·98	$05·63_2$	...	10 ...	... ...	1 ...	w.	

v. = very. w. = weak. s. = strong. diff. = diffuse.

* Tables of wave-lengths of enhanced lines (1906). The intensities of the scandium lines are Exner and Haschek's (spark).
† *Phil. Trans.*, **206**, 403–452. ‡ No origin in Rowland's ⊙. § Ascribed to Mn by Rowland.
‖ Ca Fe du in Rowland's ⊙. ¶ Ascribed to Cr in Rowland's ⊙. [ ] Lockyer's wave-length.
** Ascribed to Zr in Rowland's ⊙. The next line 4375·10, Intensity 2, may be due to Ti.
The suffixes after wave-lengths indicate the number of measures.

TABLE VIII.—*continued.*

Origin of Line.	Rowland's λ in ⊙.	Nova. Corrected λ. June 11. Plate 5266.	Nova. Corrected λ. June 12. Plate 5269.	Observed Mean λ (corrected).	Observed minus Tabular λ.	Intensity in ⊙.	Intensity. Lockyer.*	Intensity. Chromosphere (Dyson).†	Intensity. Nova. June 11.	Remarks.
Fe	4415·29	4416·73	4416·57	$4416·65_2$	...	8	...	1	s.	
Sc	15·72					3‡	20	2	diff.	
Ti_E	17·88					3	6	3		
Ti_E	43·98	44·06	$44·06_6$	$44·06_7$	+·08	5	9	6	v.s.	
Ti_E	50·65	50·77	50·89	50·83	+·18	2	3	2	s.	
?	...	63·10	58·07	62·35	+·18	...	...	...	w.	
Fe_E	62·17					3	2	...	diff.	
Ti_E	64·62		65·10			2	3	1		
Ti_E	68·66	68·62	$68·51_5$	$68·53_6$	−·13	5	9	5	s.	
He	{71·65}	70·93	71·76	$71·35_2$	−·30	...	...	7	v.s.	
Mg_E	(81·40)	81·68	81·36	$81·52_2$	+·12	...	10	1	v.s.	
Ti_E	88·49	89·11	89·19	$89·15_2$	+·23	1	5	1	w.	
Fe_E	89·35					2‡	1	3		
Fe_E	91·57	91·54	91·98	91·76	+·19	2‡	2	3	w.	
?	...	97·51	97·95	97·73	...	...	...	...	w.	
Ti_E	4501·45	4501·52	$4501·57_5$	$4501·56_6$	+·11	5	8	6	s.	
Fe_E	08·46	08·66	08·46	$08·56_2$	+·10	4	5	3	w.	
?	...	12·03	Bd 11·80	12·03	...	...	...	...	w.	
Fe	15·51	15·08	15·82	15·08	...	3‡	4	3	w.	

du	Fe_E	20·40	19·91	...	19·91	−·49	3	3	4	w.	
	Fe_E	22·80	22·58	...	22·58	−·22	3‡	6	5	w.	
	Ti_E	34·14	34·31	34·02	$34·17_2$	+·03	6	5	6	s.	
	?	...	38·95	39·91	$39·43_2$	...	...	...	...	w.	?du Fe in ⊙.
	Ti_E§	44·19	44·48	...	44·48	+·29	1‡	(3)§	0	v.w.	
	Fe_E	49·64	49·98	49·53	$49·76_2$	+·03	2	7	...	s.	
	Ti_E	49·81					6	8	8		
	Fe_E	56·06	$56·22_2$	56·11	$56·18_3$	+·12	3‡	5	4	w.	
	Cr_E	58·83	$58·60_2$	59·12	$58·77_3$	−·06	3	10	2	w.	
	Ti_E	63·94	$64·02_2$	63·70	$63·91_3$	−·03	4	7	6	s.	
	Ti_E	72·16	$72·58_2$	72·26	$72·47_3$	+·31	6	9	7	s.	
	Fe_E	76·51	76·38	...	76·38	−·13	2‡	1	1	v.w.	
	Fe_E	84·02	84·03	...	84·03	+·01	4	8	6	s.	
	Cr_E	88·38	88·12	...	88·12	−·26	3‡	10	1	w.	
	Cr_E	4618·97	4619·32	...	4619·32	+·35	4‖	3–4	1	w.	
	Fe_E	29·52	29·22	...	29·22	−·30	6	4	6	w.	
	Cr_E	34·25	34·24	...	34·24	−·01	2‡	8	2	w.	
	?	...	4731·44	...	4731·44	...	4**	...	3	w.	

v. = very. w. = weak. s. = strong. diff. = diffuse.

* Tables of wave-lengths of enhanced lines (1906). The intensities of the scandium lines are Exner and Haschek's (spark).
† *Phil. Trans.*, 206, 403–452. ‡ No origin in Rowland's ⊙. § Reese. ‖ Ascribed to iron in Rowland's ⊙.
¶ Ascribed to Ti-Co in Rowland's ⊙. ** Fe? line at 4731·65, Intensity 4. { } Runge and Paschen's wave-length.
( ) Adams' wave-length from star spectra. The suffixes after wave-lengths indicate the number of measures.

TABLE VIII.—*continued.*

Origin of Line.	Rowland's λ in ⊙.	Nova. Corrected λ. June 11. Plate 5266.	Nova. Corrected λ. June 12. Plate 5269.	Observed Mean λ (corrected).	Observed minus Tabular λ.	Intensity in ⊙.	Intensity. Lockyer.*	Intensity. Chromo-sphere (Dyson).†	Intensity. Nova. June 11.	Remarks.
Ti_E	4764·11	4763·55	...	4763·55	−·56	4	1	...	w.	
?	...	70·97	...	70·97	...	...	...	...	w.	
Ti_E	80·17	80·41	...	80·41	+·24	2§	4	1	w.	
?	...	93·98	...	93·98	...	...	...	...	v.w.	
Ti_E	4805·29	4804·53	...	4804·53	−·76	3‡	4	3	w.	
Cr_E	[12·72]	12·96	...	12·96	+·24	...	2–3	...	w.	
Cr_E	24·33	24·47	...	24·47	+·14	3‖	8	3	s.	
Cr_E	[36·40]	36·61	...	36·61	+·21	...	2–3	1	w.	
? Cr_E	48·44	? close to $H\beta^2$		...	...	2‡	6	2		
$H\beta$	61·5	62·2	...	62·2	+·7	30	...	100	v.s.	$H\beta$ line du.
Fe_E	4924·1	4924·1	...	4924·1	0·0	5	8	8	v.s.	Fe_E ,, ,,
Fe_E	5018·6	5019·4	...	5019·4	+·8	4	7	7	v.s.	,, ,, ,,
? Fe_E	5169·1	...	...	...	...	{ 3 4 }	6	4	v.s.	,, ,, ,,

v. = very. w. = weak. s. = strong. diff. = diffuse.

* Tables of wave-lengths of enhanced lines (1906). The intensities of the scandium lines are Exner and Haschek's (spark).
† *Phil. Trans.*, 206, 403-452. ‡ No origin in Rowland's ⊙. § Ascribed to Co in Rowland's ⊙.
‖ Ascribed to Fe in Rowland's ⊙. [ ] Lockyer's wave-length.

Magnitude Scale of the Bordeaux Astrographic Catalogue (Zone + 15°). By J. Jackson M.A., B.Sc., and P. J. Melotte.

(*Communicated by the Astronomer Royal.*)

The programme of work undertaken with the 26-inch refractor includes the determination of the photographic magnitudes of stars (Harvard scale) in Kapteyn's selected areas from the equator to the north pole. The fields are 40′ square and include stars to about the 14th magnitude.

The zone in declination + 15° has been completed, and this paper gives a comparison with the stars shown in the Bordeaux Astrographic Catalogue. There are 24 Kapteyn areas, but as 6 overlap 2 Bordeaux plates, there are 30 Bordeaux plates represented.

Table I. gives the difference Greenwich–Bordeaux for each star of Bordeaux plates 1002 and 986. The comparison is with the Kapteyn area in R.A. 6^h, which overlaps. These plates are given as typical.

TABLE I.

Corrections to Bordeaux Magnitudes.

	Bordeaux Magnitudes.							
	8·5.	9·0.	9·5.	10·0.	10·5.	11·0.	11·5.	12·0.
Plate 1002.	·76	·73	1·02	1·02	1·25	1·24	1·10	·69
R.A. 6^h 12^m Dec. + 15°.	·76	·63	1·23	1·18	1·43	·79	·69	
	·44	1·11	·09	1·33	1·40	·96		
Kapteyn area, 74.				·91	1·19	1·13		
				·96	1·00	1·03		
				1·12	1·30	1·13		
				1·14	1·18	1·33		
				1·20		·57		
				1·51		·88		
				1·23		1·28		
				1·30				
				1·04				
				·99				
				·53				
	$·65_3$	$·82_3$	$·78_3$	$1·10_{14}$	$1·25_7$	$1·03_{10}$	$·90_2$	$·69_1$
Plate 986.	·06	·39	1·23	1·33	·97	·91		
R.A. 6^h 20^m Dec. + 15°.			·83	·96	·88	1·00		
				1·21	·62	·49		
Kapteyn area, 74.				·80	·73	·80		
						·80		
	$·06_1$	$·39_1$	$1·03_2$	$1·08_4$	$·80_4$	$·80_5$		

Table II. gives the mean correction arranged according to magnitude for each of the 30 Bordeaux plates. The suffixes show the number of stars compared. The corrections to be applied to the Bordeaux magnitudes in order to reduce them to the Harvard scale are all positive except where otherwise stated.

TABLE II.

Corrections to be applied to Bordeaux Magnitudes (+15°) to reduce to Harvard Scale.

		Bordeaux Magnitudes.						
Plate No.	R.A.	9·0.	9·5.	10·0.	10·5.	11·0.	11·5.	9·5–11·5.
765	0	·15$_1$	·92$_2$	·76$_1$	·64$_2$	·84$_2$	·82$_3$	·82$_{10}$
348	1		1·02$_1$	1·23$_3$	·81$_2$	·87$_7$		·97$_{13}$
608	2		1·88$_1$	·87$_2$	1·08$_2$		·62$_2$	1·00$_7$
341	2		1·34$_2$		1·13$_3$	1·07$_1$	1·26$_3$	1·21$_9$
343	3		1·56$_3$		1·08$_3$	·93$_7$	·86$_4$	1·05$_{17}$
873	3				·44$_3$	·45$_3$	·58$_1$	·46$_7$
909	4		·82$_2$					·82$_2$
1000	5		1·63$_1$	1·27$_5$	1·46$_3$	1·26$_7$	1·15$_8$	1·26$_{24}$
1002	6	·82$_3$	·78$_3$	1·10$_{14}$	1·25$_7$	1·03$_{10}$	·90$_2$	1·07$_{36}$
986	6	·39$_1$	1·03$_2$	1·08$_4$	·80$_4$	·80$_5$		·93$_{15}$
1021	7	·32$_2$	·32$_2$	·87$_2$	·76$_4$	·82$_8$	·87$_7$	·78$_{23}$
1024	8	·46$_5$	·56$_1$	1·25$_3$	1·22$_3$	1·27$_3$	·70$_1$	1·14$_{11}$
1014	8	·61$_3$	·32$_3$			·82$_2$	·76$_2$	·50$_7$
1028	9	·82$_2$	1·22$_2$	1·18$_6$	1·26$_8$	1·24$_4$		1·23$_{20}$
786	10		·69$_3$		·78$_3$		·60$_1$	·72$_7$
920	11	·03$_1$		·84$_2$	·86$_3$	1·00$_1$		·88$_6$
931	12			·57$_1$	1·10$_1$	·76$_1$		·81$_3$
933	13	·54$_2$		1·24$_1$				1·24$_1$
641	13	·92$_2$	·37$_1$					·37$_1$
943	14			·01$_3$	·64$_2$	·31$_2$		·28$_7$
949	15	·36$_1$	·91$_1$	·45$_3$	·56$_2$	·64$_3$	·74$_1$	·60$_{10}$
709	16		·49$_2$	1·09$_1$	·77$_1$	·34$_3$		·55$_7$
714	17	·73$_3$		1·03$_4$	1·23$_9$	·82$_7$	·87$_3$	1·03$_{23}$
820	18			·51$_5$	·22$_3$	·26$_1$	−·20$_2$	·28$_{11}$
821	19			·56$_3$	·17$_1$	·02$_2$		·32$_6$
1051	19			·51$_8$	·56$_7$	·62$_5$	·31$_2$	·53$_{22}$
856	20	−·46$_3$	·01$_4$	·56$_9$	·32$_8$	·30$_{10}$	·39$_{10}$	·36$_{41}$
755	21	·56$_1$	·75$_3$	·98$_4$	1·01$_7$	·56$_2$	·62$_2$	·87$_{18}$
740	22		1·50$_1$	1·22$_2$	1·05$_8$	·81$_{16}$	·73$_1$	·93$_{28}$
745	23		1·26$_2$	1·75$_1$	1·14$_8$	1·26$_2$	·58$_2$	1·14$_{10}$
Mean.		·47$_{30}$	·83$_{42}$	·88$_{87}$	·91$_{102}$	·80$_{114}$	·74$_{57}$	·84$_{402}$

It will be seen from this comparison that the mean correction to the Bordeaux magnitudes is $+0^{m}\cdot84$ between $9^{m}\cdot5$ and $11^{m}\cdot5$ (Bordeaux). This is the mean for 402 stars. Between these limits of magnitude the correction shows satisfactory constancy for each plate. For different plates, however, there is a range from $0^{m}\cdot28$ to $1^{m}\cdot26$.

Thus if a mean correction of $+\cdot84$ be applied to the Bordeaux plates, the magnitudes of any one plate show a mean discordance of $\pm^{m}\cdot25$, with a possible range of half a magnitude either way.

On a Short Table for directly converting Estimates of Brightness into Stellar Magnitudes on Pogson's Scale. By Dr. Arthur A. Rambaut, F.R.S., Radcliffe Observer.

In a great many cases the magnitude of a new or variable star is determined by measuring, or estimating, its brightness relatively to two reference stars, one brighter and the other fainter than the variable. If, as not infrequently happens, the magnitude is deduced by simply interpolating between the magnitudes of the comparison stars, an error will always be introduced of greater or less importance according to the difference in brightness between the comparison stars. An experienced observer will always endeavour to choose comparison stars, so that this difference may be as small as possible in order to reduce the error to a minimum, and in the vast majority of cases the inaccuracy so introduced is small and may quite safely be neglected. But it sometimes happens that suitable comparison stars cannot easily be found, and in the case of new stars, when the available comparison stars may easily differ by as much as one or more magnitudes—as in the case of *Nova Aquilæ No.* 3 when near its brightest,—the errors introduced by this inaccurate method of reduction become much too serious to be overlooked, and may easily amount to half a magnitude or so.

In such cases, if the observer is certain that it is in respect of *brightness* that the comparison is made, he must, in order to render his results accurate, have recourse to light-ratios.

If the observations were such as to give directly the ratio of the brightness of the variable to that of a comparison star, their difference in magnitude might be at once deduced without difficulty. But the observations are usually so arranged that the difference in brightness of one pair of stars is compared with that of another pair. As generally expressed

$$A\,1\,V\,2\,B \quad . \quad . \quad . \quad . \quad (1)$$

denotes that the difference between the variable, V, and one of the comparison stars, A, is to the difference between the other com-

parison star, B, and the variable in the ratio 1 : 2, or that the difference between V and A is one-third of that between B and A. Except that the number of parts into which the interval between A and B is divided is usually small (as in the above example), this is essentially the same as the method employed for the eye-estimates in the Harvard Photometry (*H.A.*, **14**); that is to say, "the interval in brightness between the two comparison stars is regarded as a unit with decimal subdivisions, and the place of the third star upon the scale thus formed is estimated by the observer."

If, then, we denote the magnitudes of the comparison stars by m and n (m being the magnitude of the *fainter* star and therefore numerically larger than n), and if we take V to denote the magnitude of the variable or new star, and if I_m, I_n, I_V denote the intensities, or brightnesses, of the same three stars respectively, then an observation gives us a relation of the form

$$I_n - I_V = k(I_n - I_m) \quad . \quad . \quad . \quad . \quad (2)$$

where k is a positive number less than unity.

If P be such that $\log P = 0{\cdot}4$, we have on Pogson's scale

$$I_m \times P^m = C,$$

where C is a constant and m may have any value whatever. The value of C will depend on the standard which we adopt as unit of brightness. A convenient standard for this purpose is the brightness of a star of zero magnitude. If we adopt this convention we shall have $C = 1$ and

$$I_m \times P^m = 1, \quad \text{or} \quad I_m = P^{-m}.$$

Table I. contains the values of I_m computed from this formula for values of m from 0·0 to 2·5. Beyond this it is unnecessary to go, for if m lies outside this range it can always be written in the form

$$m = y + 2{\cdot}5 \times r,$$

where r is an integer (positive or negative) and y lies within the range. Thus

$$I_m = P^{-m} = P^{-y-2{\cdot}5\times r} = P^{-y} \times P^{-2{\cdot}5\times r} = \frac{I_y}{P^{2{\cdot}5\times r}}.$$

But $P^{2{\cdot}5} = 10$. Hence $I_m = \dfrac{I_y}{(10)^r}$.

The value of I_y is taken directly from Table I., and from this quantity I_m is at once deduced on division by 10^r, *i.e.* by moving the decimal point r places to left or right according as r is positive or negative.

This table of relative brightnesses, in terms of the brightness of a zero magnitude star taken as unity, may, I think, be of use in

many researches dealing with the magnitudes of stars. By means of it we might obtain the value of I_V (and hence that of V) from equation (2) as it stands, but this mode of procedure would be extremely cumbersome in practice. We may, however, put this equation in another form, from which the result can be deduced in a much more simple and direct manner.

If we assume Δn such that

$$V = n + \Delta n,$$

equation (2) becomes

$$P^{-n} - P^{-V} = k(P^{-n} - P^{-m}),$$

or, multiplying by P^n,

$$\{1 - P^{-\Delta n}\} = k\{1 - P^{-(m-n)}\} \quad . \quad . \quad . \quad (3)$$

The form of this equation shows that Δn is a function of the two quantities $(m-n)$ and k, or that, being given k and the *difference* of the magnitudes of the comparison stars, the correction Δn is determined whatever the separate values of m and n may be. By means of this equation the quantity Δn can be very easily deduced with the help of Table II. This table is formed by subtracting each of the quantities in Table I. from unity, and exhibits the values of $1 - P^{-m}$ for values of m from 0·0 to 2·5.

Thus to find Δn, being given $m-n$ and k, we enter Table II. with $m-n$ as argument and find the quantity $1 - P^{-(m-n)}$. Multiplying this by k, we find the quantity $1 - P^{-\Delta n}$, which, in the same table, corresponds to the argument Δn. Thus Δn is determined.

For example, if we are given $m = 9{\cdot}74$, $n = 7{\cdot}53$, and $k = 0{\cdot}3$, we have $m - n = 2{\cdot}21$. With this value we find from Table II.,

$$1 - P^{-(m-n)} = 0{\cdot}8694$$

and

$$k\{1 - P^{-(m-n)}\} = 0{\cdot}3 \times 0{\cdot}8694 = 0{\cdot}2608,$$

which in the table corresponds to the argument 0·328. Thus we have

$$\begin{aligned} n &= 7{\cdot}53 \\ \Delta n &= 0{\cdot}328 \\ \therefore\ V = n + \Delta n &= 7{\cdot}858. \end{aligned}$$

If the observation is not made in the decimal form, but is recorded, as is perhaps more usual, in the form

$$A p V q B,$$

where A and B are the comparison stars and p, q two small integer numbers, then if A is the brighter comparison star we have only to write $p/(p+q)$ for k, or, if B is the brighter, $q/(p+q)$ for k, and the result is deduced in an exactly similar manner. *E.g.*, if

we are given the magnitudes of the comparison stars as in the preceding example, and if the observation is recorded

A 1 V 2 B,

we have $p = 1$, $q = 2$ $\therefore$ $p/(p+q) = 1/3$, and $m - n = 2^{\cdot}21$. As before, from Table II. we take

$$1 - P^{-(m-n)} = 0^{\cdot}8694$$

$$\frac{p}{p+q}\{1 - P^{-(m-n)}\} = \tfrac{1}{3} \times 0^{\cdot}8694 = 0^{\cdot}2898.$$

Hence

$$\triangle n = 0^{\cdot}372.$$

In Table III. are exhibited the values of Δn computed from equation (3) for each tenth of a unit in the value of k, and for each tenth of a magnitude in the difference $m - n$, from $0^{m}{\cdot}1$ to $2^{m}{\cdot}0$. By the aid of this table the computation of the magnitude of a star whose brightness has been compared with that of two comparison stars (differing by not more than two whole magnitudes) becomes at least as easy as the simple interpolation between the two magnitudes could be, while it possesses the advantage of giving the result *correctly* whatever be the range in magnitude (within the limits of the table) between the comparison stars.

Table I.

Table for I_m where $I_m = P^{-m}$ and $\log P = 0{\cdot}4$.

Mag.	0	Diff.	1	Diff.	2	Diff.	3	Diff.	4	Diff.	5	Diff.	6	Diff.	7	Diff.	8	Diff.	9	Diff.	10
0·0	1·0000	92	0·9908	91	·9817	90	·9727	89	·9638	88	·9550	88	·9462	86	·9376	86	·9290	86	·9204	84	·9120
0·1	0·9120	84	·9036	82	·8954	82	·8872	82	·8790	80	·8710	80	·8630	79	·8551	79	·8472	77	·8395	77	·8318
0·2	·8318	77	·8241	75	·8166	75	·8091	74	·8017	74	·7943	73	·7870	72	·7798	71	·7727	71	·7656	70	·7586
0·3	·7586	70	·7516	69	·7447	68	·7379	68	·7311	67	·7244	66	·7178	66	·7112	65	·7047	65	·6982	64	·6918
0·4	·6918	63	·6855	63	·6792	62	·6730	62	·6668	61	·6607	61	·6546	60	·6486	59	·6427	59	·6368	58	·6310
0·5	·6310	58	·6252	58	·6194	56	·6138	57	·6081	55	·6026	56	·5970	54	·5916	55	·5861	53	·5808	54	·5754
0·6	·5754	52	·5702	53	·5649	51	·5598	52	·5546	51	·5495	50	·5445	50	·5395	49	·5346	49	·5297	49	·5248
0·7	·5248	48	·5200	48	·5152	47	·5105	47	·5058	46	·5012	46	·4966	46	·4920	45	·4875	44	·4831	45	·4786
0·8	·4786	44	·4742	43	·4699	43	·4656	43	·4613	42	·4571	42	·4529	42	·4487	41	·4446	40	·4406	41	·4365
0·9	·4365	40	·4325	40	·4285	39	·4246	39	·4207	38	·4169	39	·4130	37	·4093	38	·4055	37	·4018	37	·3981
1·0	·3981	36	·3945	37	·3908	35	·3873	36	·3837	35	·3802	35	·3767	34	·3733	35	·3698	34	·3664	33	·3631
1·1	·3631	34	·3597	32	·3565	33	·3532	33	·3499	32	·3467	31	·3436	32	·3404	31	·3373	31	·3342	31	·3311
1·2	·3311	30	·3281	30	·3251	30	·3221	29	·3192	30	·3162	29	·3133	28	·3105	29	·3076	28	·3048	28	·3020
1·3	·3020	28	·2992	27	·2965	27	·2938	27	·2911	27	·2884	26	·2858	27	·2831	26	·2805	25	·2780	26	·2754
1·4	·2754	25	·2729	25	·2704	25	·2679	24	·2655	25	·2630	24	·2606	24	·2582	23	·2559	24	·2535	23	·2512
1·5	·2512	23	·2489	23	·2466	23	·2443	22	·2421	22	·2399	22	·2377	22	·2355	22	·2333	21	·2312	21	·2291
1·6	·2291	21	·2270	21	·2249	21	·2228	20	·2208	20	·2188	20	·2168	20	·2148	20	·2128	19	·2109	20	·2089
1·7	·2089	19	·2070	19	·2051	19	·2032	18	·2014	19	·1995	18	·1977	18	·1959	18	·1941	18	·1923	18	·1905
1·8	·1905	17	·1888	17	·1871	17	·1854	17	·1837	17	·1820	17	·1803	17	·1786	16	·1770	16	·1754	16	·1738
1·9	·1738	16	·1722	16	·1706	16	·1690	15	·1675	15	·1660	16	·1644	15	·1629	15	·1614	14	·1600	15	·1585
2·0	·1585	15	·1570	14	·1556	14	·1542	14	·1528	14	·1514	14	·1500	14	·1486	14	·1472	13	·1459	14	·1445
2·1	·1445	13	·1432	13	·1419	13	·1406	13	·1393	13	·1380	12	·1368	13	·1355	12	·1343	13	·1330	12	·1318
2·2	·1318	12	·1306	12	·1294	12	·1282	11	·1271	12	·1259	12	·1247	11	·1236	11	·1225	12	·1213	11	·1202
2·3	·1202	11	·1191	11	·1180	11	·1169	10	·1159	11	·1148	10	·1138	11	·1127	10	·1117	10	·1107	11	·1096
2·4	·1096	10	·1086	10	·1076	9	·1067	10	·1057	10	·1047	9	·1038	10	·1028	9	·1019	10	·1009	9	·1000

Table II.

Table for $\{1 - P^{-m}\}$.

Mag.	0	Diff.	1	Diff.	2	Diff.	3	Diff.	4	Diff.	5	Diff.	6	Diff.	7	Diff.	8	Diff.	9	Diff.	10
0·0	0·0000	92	·0092	91	·0183	90	·0273	89	·0362	88	·0450	88	·0538	86	·0624	86	·0710	86	·0796	84	·0880
0·1	·0880	84	·0964	82	·1046	82	·1128	82	·1210	80	·1290	80	·1370	79	·1449	79	·1528	77	·1605	77	·1682
0·2	·1682	77	·1759	75	·1834	75	·1909	74	·1983	74	·2057	73	·2130	72	·2202	71	·2273	71	·2344	70	·2414
0·3	·2414	70	·2484	69	·2553	68	·2621	68	·2689	67	·2756	66	·2822	66	·2888	65	·2953	65	·3018	64	·3082
0·4	·3082	63	·3145	63	·3208	62	·3270	62	·3332	61	·3393	61	·3454	60	·3514	59	·3573	59	·3632	58	·3690
0·5	·3690	58	·3748	58	·3806	56	·3862	57	·3919	55	·3974	56	·4030	54	·4084	55	·4139	53	·4192	54	·4246
0·6	·4246	52	·4298	53	·4351	51	·4402	52	·4454	51	·4505	50	·4555	50	·4605	49	·4654	49	·4703	49	·4752
0·7	·4752	48	·4800	48	·4848	47	·4895	47	·4942	46	·4988	46	·5034	46	·5080	45	·5125	44	·5169	45	·5214
0·8	·5214	44	·5258	43	·5301	43	·5344	43	·5387	42	·5429	42	·5471	42	·5513	41	·5554	40	·5594	41	·5635
0·9	·5635	40	·5675	40	·5715	39	·5754	39	·5793	38	·5831	39	·5870	37	·5907	38	·5945	37	·5982	37	·6019
1·0	·6019	36	·6055	37	·6092	35	·6127	36	·6163	35	·6198	35	·6233	34	·6267	35	·6302	34	·6336	33	·6369
1·1	·6369	34	·6403	32	·6435	33	·6468	33	·6501	32	·6533	31	·6564	32	·6596	31	·6627	31	·6658	31	·6689
1·2	·6689	30	·6719	30	·6749	30	·6779	29	·6808	30	·6838	29	·6867	28	·6895	29	·6924	28	·6952	28	·6980
1·3	·6980	28	·7008	27	·7035	27	·7062	27	·7089	27	·7116	26	·7142	27	·7169	26	·7195	25	·7220	26	·7246
1·4	·7246	25	·7271	25	·7296	25	·7321	24	·7345	25	·7370	24	·7394	24	·7418	23	·7441	24	·7465	23	·7488
1·5	·7488	23	·7511	23	·7534	23	·7557	22	·7579	22	·7601	22	·7623	22	·7645	22	·7667	21	·7688	21	·7709
1·6	·7709	21	·7730	21	·7751	21	·7772	20	·7792	20	·7812	20	·7832	20	·7852	20	·7872	19	·7891	20	·7911
1·7	·7911	19	·7930	19	·7949	19	·7968	18	·7986	19	·8005	18	·8023	18	·8041	18	·8059	18	·8077	18	·8095
1·8	·8095	17	·8112	17	·8129	17	·8146	17	·8163	17	·8180	17	·8197	17	·8214	16	·8230	16	·8246	16	·8262
1·9	·8262	16	·8278	16	·8294	16	·8310	15	·8325	15	·8340	16	·8356	15	·8371	15	·8386	14	·8400	15	·8415
2·0	·8415	15	·8430	14	·8444	14	·8458	14	·8472	14	·8486	14	·8500	14	·8514	14	·8528	13	·8541	14	·8555
2·1	·8555	13	·8568	13	·8581	13	·8594	13	·8607	13	·8620	12	·8632	13	·8645	12	·8657	13	·8670	12	·8682
2·2	·8682	12	·8694	12	·8706	12	·8718	11	·8729	12	·8741	12	·8753	11	·8764	11	·8775	12	·8787	11	·8798
2·3	·8798	11	·8809	11	·8820	11	·8831	10	·8841	11	·8852	10	·8862	11	·8873	10	·8883	10	·8893	11	·8904
2·4	·8904	10	·8914	10	·8924	9	·8933	10	·8943	10	·8953	9	·8962	10	·8972	9	·8981	10	·8991	9	·9000

TABLE III.

Table for Δn being given $\{1 - P^{-\Delta n}\} = k\{1 - P^{-(m-n)}\}$.

$\frac{k}{m-n}$	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0
0·1	0·010	0·019	0·029	0·039	0·049	0·059	0·069	0·079	0·090	0·100
	8	18	27	37	46	56	67	78	88	
0·2	·018	·037	·056	·076	·095	·115	·136	·157	·178	·200
	8	17	26	34	45	55	65	76	88	
0·3	·026	·054	·082	·110	·140	·170	·201	·233	·266	·300
	8	15	23	33	42	52	63	74	87	
0·4	·034	·069	·105	·143	·182	·222	·264	·307	·353	·400
	7	14	22	30	39	50	62	73	85	
0·5	·041	·083	·127	·173	·221	·272	·324	·380	·438	·500
	6	13	21	29	38	47	59	71	85	
0·6	·047	·096	·148	·202	·259	·319	·383	·451	·523	·600
	6	12	19	27	36	45	56	68	83	
0·7	·053	·108	·167	·229	·295	·364	·439	·519	·606	·700
	5	12	18	25	33	43	54	67	82	
0·8	·058	·120	·185	·254	·328	·407	·493	·586	·688	·800
	5	10	16	23	31	41	52	65	80	
0·9	·063	·130	·201	·277	·359	·448	·545	·651	·768	0·900
	4	9	15	22	30	38	49	62	79	
1·0	·067	·139	·216	·299	·389	·486	·594	·713	·847	1·000
	5	9	14	20	27	37	47	60	77	
1·1	·072	·148	·230	·319	·416	·523	·641	·773	0·924	1·100
	3	8	13	19	26	34	45	59	76	
1·2	·075	·156	·243	·338	·442	·557	·686	·832	1·000	1·200
	4	7	12	17	24	32	42	56	74	
1·3	·079	·163	·255	·355	·466	·589	·728	·888	1·074	1·300
	3	7	11	17	22	30	40	53	72	
1·4	·082	·170	·266	·372	·488	·619	·768	·941	1·146	1·400
	3	6	10	14	21	29	38	51	71	
1·5	·085	·176	·276	·386	·509	·648	·806	0·992	1·217	1·500
	2	6	10	14	20	26	36	49	68	
1·6	·087	·182	·286	·400	·529	·674	·842	1·041	1·285	1·600
	2	5	8	13	18	25	34	47	67	
1·7	·089	·187	·294	·413	·547	·699	·876	1·088	1·352	1·700
	3	5	8	12	16	23	32	45	64	
1·8	·092	·192	·302	·425	·563	·722	·908	1·133	1·416	1·800
	2	4	7	11	16	21	29	42	62	
1·9	·094	·196	·309	·436	·579	·743	·937	1·175	1·478	1·900
	1	4	7	10	14	20	28	39	59	
2·0	·095	·200	·316	·446	·593	·763	·965	1·214	1·537	2·000

The Dark Markings of the Sky. By Rev. T. E. Espin.

Professor E. E. Barnard has lately published in *The Astrophysical Journal*, 49, 1 (1919), a catalogue of 182 dark markings in the sky, and it is very interesting to find that he seems to have established the fact that many of them are due to the obscuring presence of a nebula. Under the heading of a "Remarkable Object in Perseus" (*M.N.*, 58, 334 (1898)), I gave an account of the discovery of one of these, and although at the time it was generally held to be merely a dark opening in the Milky Way, I never felt the least doubt that the hazy appearance found in 1898 was no delusion.

When examining zone $+44^{\circ}$ in 1915 for new double stars I came across another of these objects with the 24-in. reflector, and I find that it is not given in Professor Barnard's list. The following is the original observation :—

1915 Nov. 27, I found something exactly like what I found in Perseus. It is at $20^{h}\ 44^{m} + 44^{\circ}\ 0'$ (1855). It seems oval with P. 45° for longer axis, and 10′ in length by 5′. There are no stars in it, and it appeared as a reddish haze.

Mean Areas and Heliographic Latitudes of Sun-spots in the Years 1915 *and* 1916.

(*Communicated by the Astronomer Royal.*)

The results here given are in continuation of those printed in the *Monthly Notices*, 76, 400, and are deduced from the measurements of photographs taken at the Royal Observatories of Greenwich and of the Cape; and in India, at the Kodaikánal Observatory, and at Dehra Dûn, North-West Provinces.

Table I. gives the mean daily area of umbræ, whole spots, and faculæ for each synodic rotation of the Sun in the two years 1915 and 1916, and Table II. gives the same particulars for each of the entire years, 1913 to 1916 inclusive. The areas are given in two forms: first, projected areas, that is to say, as seen and measured on the photographs, these being expressed in millionths of the Sun's apparent disc; and next, areas as corrected for foreshortening, the areas in this case being expressed in millionths of the Sun's visible hemisphere.

Table III. exhibits for each rotation in the years 1915 and 1916 the mean daily area of the whole spots (corrected for foreshortening), and the mean heliographic latitude of the spotted areas for spots north and for spots south of the equator, together with the mean heliographic latitude of the entire spotted area, and the mean distance from the equator of all spots; and Table IV.

TABLE I.

No. of Rotation.	Date of Commencement of each Rotation.	No. of Days on which Photographs were taken.	Mean of Daily Areas.					
			Projected.			Corrected for Foreshortening.		
			Umbræ.	Whole Spots.	Faculæ.	Umbræ.	Whole Spots.	Faculæ.
	1915. d	d						
820	Jan. 8·41	28	57	260	867	48	226	1046
821	Feb. 4·76	27	210	957	922	165	750	1100
822	Mar. 4·09	27	102	488	1018	84	406	1182
823	Mar. 31·40	28	270	1294	1073	182	982	1276
824	Apr. 27·67	27	131	627	1013	105	530	1205
825	May 24·89	27	198	914	806	136	639	977
826	June 21·09	27	337	1736	1258	244	1306	1521
827	July 18·29	28	354	1764	1961	254	1294	2262
828	Aug. 14·51	27	273	1261	1929	195	930	2164
829	Sept. 10·76	27	158	746	1760	115	556	2037
830	Oct. 8·04	28	176	971	1405	123	705	1681
831	Nov. 4·33	27	101	515	1611	79	428	1926
832	Dec. 1·64	27	69	398	1221	52	328	1528
833	Dec. 28·97	27	132	785	1396	93	572	1609
	1916.							
834	Jan. 25·31	28	182	1006	1607	124	711	1851
835	Feb. 21·65	27	215	1031	1618	163	786	1956
836	Mar. 19·97	27	225	1335	1940	156	965	2320
837	Apr. 16·25	28	196	1093	2093	143	815	2308
838	May 13·49	27	287	1300	1218	217	991	1429
839	June 9·70	26	296	1487	1354	206	1049	1544
840	July 6·90	27	177	868	1417	122	603	1625
841	Aug. 3·11	28	93	474	1145	69	360	1393
842	Aug. 30·35	27	115	624	1371	90	518	1617
843	Sept. 26·61	27	185	1029	1100	132	751	1359
844	Oct. 23·90	27	158	837	1626	107	574	1956
845	Nov. 20·21	28	149	802	1485	109	603	1825
846	Dec. 17·53	27	324	1756	1944	240	1323	2383

TABLE II.

Year.	No. of Days on which Photographs were taken	Mean of Daily Areas.					
		Projected			Corrected for Foreshortening.		
		Umbræ.	Whole Spots.	Faculæ.	Umbræ.	Whole Spots.	Faculæ.
	d						
1913	365	2	10	87	1	7	95
1914	365	40	195	396	31	152	454
1915	365	186	920	1289	137	697	1521
1916	365	187	979	1502	135	723	1660

TABLE III.

No. of Rotation.	Date of Commencement of each Rotation.		No. of Days on which Photographs were taken.	Spots NORTH of the Equator.		Spots SOUTH of the Equator.		Mean Heliographic Latitude of entire Spotted Area.	Mean Distance from Equator of all Spots.
				Mean of Daily Areas.	Mean Heliographic Latitude.	Mean of Daily Areas.	Mean Heliographic Latitude.		
	1915.	d	d						
820	Jan.	8·41	28	167	17°·28	60	20°·95	+ 7°·18	18°·25
821	Feb.	4·76	27	350	21·57	399	21·50	− 1·37	21·53
822	Mar.	4·09	27	272	22·41	134	20·42	+ 8·28	21·75
823	Mar.	31·40	28	790	18·96	192	21·28	+11·11	19·41
824	Apr.	27·67	27	419	19·87	111	18·66	+11·80	19·62
825	May	24·89	27	462	15·97	177	20·71	− 5·82	17·28
826	June	21·09	27	441	17·84	866	21·05	− 7·93	19·96
827	July	18·29	28	253	19·15	1041	18·75	−11·33	18·83
828	Aug.	14·51	27	479	21·61	452	18·17	+ 2·30	19·94
829	Sept.	10·76	27	461	11·76	95	18·99	+ 6·51	13·00
830	Oct.	8·04	28	463	15·70	242	16·19	+ 4·76	15·87
831	Nov.	4·33	27	177	19·50	250	21·84	− 4·70	20·87
832	Dec.	1·64	27	151	11·51	177	19·43	+ 5·20	15·79
833	Dec.	28·97	27	313	14·95	259	17·15	+ 0·41	15·93
	1916.								
834	Jan.	25·31	28	330	14·47	381	17·08	− 2·42	15·87
835	Feb.	21·65	27	241	19·70	545	17·54	− 6·13	18·22
836	Mar.	19·97	27	800	14·08	165	15·16	+ 9·07	14·26
837	Apr.	16·25	28	465	13·64	349	20·58	− 1·01	16·60
838	May	13·49	27	429	12·87	562	13·37	− 2·20	12·97
839	June	9·70	26	711	12·58	339	14·23	+ 3·93	13·12
840	July	6·90	27	588	12·30	15	23·24	+11·45	12·56
841	Aug.	3·11	28	325	15·90	35	15·44	+12·86	15·86
842	Aug.	30·35	27	430	21·63	88	15·09	+15·37	20·48
843	Sept.	26·61	27	673	16·43	78	18·17	+12·85	16·61
844	Oct.	23·90	27	387	15·19	187	18·32	+ 4·28	16·21
845	Nov.	20·21	28	328	20·34	275	17·85	+ 2·93	19·21
846	Dec.	17·53	27	1106	13·98	217	20·02	+ 8·39	14·97

TABLE IV.

Year.	No. of Days on which Photographs were taken.	Spots NORTH of the Equator.		Spots SOUTH of the Equator.		Mean Heliographic Latitude of entire Spotted Area.	Mean Distance from Equator of all Spots.
		Mean of Daily Areas.	Mean Heliographic Latitude.	Mean of Daily Areas.	Mean Heliographic Latitude.		
	d						
1913	365	5	24°·81	2·5	20°·08	+9°·81	23°·23
1914	365	99	21·11	53	23·06	+5·71	21·79
1915	365	379	17·95	318	19·75	+0·77	18·77
1916	365	468	15·11	255	16·79	+3·88	15·70

gives the same information for each year as a whole for the years 1913 to 1916 inclusive. Tables II. and IV. are thus in continuation of the similar tables for the years 1874 to 1888 on pp. 381 and 382 of vol. xlix. of the *Monthly Notices*; and for the years 1889 to 1902 on pp. 465 and 466 of vol. lxiii., and for the years 1901 to 1914 on pp. 402 and 403 of vol. lxxvi.

The rotations in Table I. and Table III. are numbered in continuation of Carrington's series (*Observations of Solar Spots made at Redhill*, by R. C. Carrington, F.R.S.), No. 1 being the rotation commencing 1853 November 9. The assumed prime meridian is that which passed through the ascending node at mean noon of 1854 January 1, and the assumed period of the sun's sidereal rotation is 25·38 days. The dates of the commencement of the rotations are given in Greenwich civil time, reckoning from mean midnight.

The principal features of the record for the two years 1915 and 1916 are:—

1. In 1915 the increase of the spotted area, which was so strikingly manifested in 1914, was continued yet further, the mean daily spotted areas for the three years 1913 to 1915 being respectively 7, 152, and 697. But in 1916 this progress came nearly to a standstill, the spotted area for that year being under 4 per cent. in excess of its extent for 1915. A halt of this character, lasting for many months, and taking place during the rise from minimum towards maximum, is unusual. A fresh revival, however, commenced in the last week of 1916.

2. The results for the separate rotations show that after the prolonged quiescence of 1913 the energy of the new cycle first came into manifestation with the appearance at the east limb of the sun of Group 7030 on 1914 March 30, and developed in a series of nearly regular oscillations of increasing extent, and average duration of about a calendar month. These oscillations culminated in an important secondary maximum in the summer of 1915, after which the oscillations were less regular and of smaller extent, until 1916, in which year two further but less important secondary maxima were observed, one in the spring and the other at midsummer. The autumn of 1916 was marked by a period of diminished activity lasting, as noted above, until the last week of the year.

3. As usual, the variations in the extent of the faculæ were relatively less than in the extent of the spotted area. But the second of the three subordinate maxima referred to in the preceding paragraph was accompanied by a great display of faculæ, which also showed great activity throughout the three last weeks of 1916 December.

4. Comparing the two hemispheres, the preponderance still remained with the northern spots, 65 per cent. of the total spotted area lying in the northern hemisphere for 1914 and again for 1916. But in 1915 there was a nearer approach to equality; the

figures appearing as 54 per cent. northern against 46 southern. In the first six months of 1916 practically the same proportion was maintained; but there was a curious failure of southern activity in the latter half of the year, a failure which was mainly accountable for the halt in the progress of the general spot-activity that was presented by 1916. The northern hemisphere, on the other hand, continued to show an increase in spotted area throughout the year.

5. The mean distance of all spots from the equator, and the mean daily spotted area for 1915, corresponded closely with the figures obtained for the year 1881, two years before the maximum of 1883. The great fall in the distance from the equator registered for 1916—15°·70 as against 18°·78 for 1915—points to the near approach of the maximum, which generally accords with a distance from the equator of 13° or 14°.

6. The sun was free from spots on five days in 1915 and on four in 1916. The days without spots in 1913 and 1914 were 311 and 143 respectively.

7. An unusual number of very small spots seen only on one day were measured on the photographs in the last quarter of 1914 and throughout 1915. These were especially numerous upon photographs taken at the Royal Observatory, Cape of Good Hope, for, since the two photographs taken daily at that Observatory were usually exposed at a much shorter interval of time apart than the two taken at Greenwich, a spot lasting only for a few minutes had a better chance of appearing on two Cape photographs, and so of being accepted for measurement, than it had of appearing on two Greenwich photographs. In this way a considerable number of markings were measured during these months fainter and more evanescent than had previously been generally accepted. Some of these fainter markings proved to be of especial interest, since they were situated in latitudes far outside the ordinary spot-zones. As no uniform and systematic search has been made in high latitudes for these difficult and transitory objects, no spots distant more than 50° from the equator have been included in the foregoing tables and notes, but a special paper dealing with some of them was communicated to the Society by Mrs. Maunder on 1917 June 8 (*Monthly Notices*, 77, 621).

Apart from these high latitude "flecks," the number of separate groups of spots observed was 474 in 1915 and 513 in 1916, as compared with 118 in 1914. Of these, the groups observed only on one day numbered 50 in 1914, 212 in 1915, and 174 in 1916.

8. Of the 474 groups of 1915, 250 were in the northern hemisphere, of which 114 were seen only on one day, and 136 for a longer time. Of the southern groups, 224 in number, 98 were on one day, and 126 lasted longer. In 1916, 296 groups in the northern hemisphere were divided into 90 with a single appearance, and 206 of longer duration; while the 217 southern groups comprised 84 of one day, and 133 of two or more days. The

proportion of northern groups of all durations has therefore increased slightly in the three years, especially amongst those lasting for more than one day. The 50 ephemeral groups of 1914 were equally divided between the two hemispheres.

Royal Observatory, Greenwich:
1919 *January.*

Notes on Some of the Sun-spots measured at the Royal Observatory, Greenwich, on Photographs of the Sun taken in the Year 1915. By E. Walter Maunder. (Plates 7–11.)

(*Communicated by the Astronomer Royal.*)

The preceding note—*Mean Areas and Heliographic Latitudes of Sun-spots in the Years* 1915 *and* 1916—calls for some additional remarks, since for the year 1916 an important departure was made from the method of computation employed for the year 1915 and for the preceding years of the *Greenwich Photo-Heliographic Results.*

This change was rendered necessary by the great reduction in the staff of the Heliographic Department at the time that the Sun was displaying a rapid increase in spot-activity. It was no longer possible to prevent the measurement of the solar photographs from falling much into arrear and the reduction of the measures from being still further belated. Under these conditions the different sections into which the *Greenwich Photo-Heliographic Results* are divided in their published form were reviewed, and it was decided that—for the present—an important saving of labour might be secured in the following manner:—

The *Greenwich Photo-Heliographic Results* are published in four sections. Section I. is in the form of a *Journal*, and gives for each photograph of the Sun measured—one photograph being selected for measurement for each day—the polar co-ordinates of each spot and group of faculæ, and their equivalent heliographic Longitudes and Latitudes, together with the areas of umbræ, whole spots, and faculæ, corrected for foreshortening and reduced to a uniform scale. In the case of groups containing a large number of small members the smaller spots have not been all measured separately, but have been combined, as convenient, into subordinate clusters of small spots close together, the position of the "centre of gravity" and the aggregate area of each such subordinate cluster being treated as if for a single spot. The more complex groups are, therefore, represented not by a single series of figures expressing the mean position and total area of an entire group as a single entity, but by several sets expressing these data for each of the measured components of the group, whether such components are individual spots or subordinate clusters of spots.

Section II. is in the form of a *Ledger*, and presents the position and area, not of the component members of each spot-group, but of each spot-group as a whole, as a complete and separate entity. Each group is treated by itself; its position and area being given for each day that it was under observation. And the position adopted for any group for a particular day was that of the "centre of gravity" of the component members; that is to say, it was derived from the separate positions of the various components by taking the mean, weighted according to the area of each member.

Section III. is a small one, and contains a *Catalogue of Recurrent Groups* compiled from the *Ledger*.

Section IV. contains a Table of Total Daily Areas, giving for each day of the year the total areas of umbræ, whole spots, and faculæ; first, as seen projected on the apparent disc of the Sun, and, next, as corrected for foreshortening. This table is followed by four others that are identical in character with the four tables of the preceding Note—*Mean Heliographic Areas*, etc. Section IV. therefore supplies an *Annual Summary* of results.

Sections III. and IV. are of obvious usefulness, are easily derived from the reductions necessary for the preparation of Sections I. and II., and occupy but little space in the printed volume.

Of Sections I. and II. the second, the *Ledger*, has proved much the more useful as a basis for further statistical inquiry. It is from the *Ledger* that the material has been drawn for deducing the mean rotation period of the Sun as a whole, and those of different latitudes in particular. It is from the *Ledger* that the mean latitude of the spotted area north and south of the equator has been determined, and the want of symmetry in the numbers and areas of spots east and west of the central meridian of the Sun's disc has been detected, and the position of the solar axis verified. In the *Ledger* there are also given the longitude from the central meridian of each group day by day, the heliographic longitude of the group computed, not only on the basis of a mean rotation-period of the Sun, but also on that of a period computed for the special latitude of the group, and the *Total Area* of each group is shown, both as actually seen *Projected* on the Sun as a disc and as *Corrected for Foreshortening*.

The computations for forming the *Ledger*, though very simple, take up much space and demand a considerable time. It was, therefore, suggested that during the process of measuring the solar photographs of 1916, beside the usual measures, an additional pointing should be made on the "centre of gravity" of each separate group, as estimated in the micrometer. This has accordingly been done for the year 1916, and these positions of the centres of gravity of the spot-groups have hitherto been the only positions reduced for 1916: the measures of the positions of the component parts of the groups have been made as usual, and are duly entered in the measuring books, being thus ready for reduction in the future, when desired, but nothing has been so far done with

them. The labour of the reduction of the measures of the component members of groups—perhaps three-fourths of this portion of the work—has been saved for the present, and with it the entire labour hitherto expended on the preparation of the *Ledger*; the Ledger for 1916 being prepared directly from the reduction of the estimation of the position of the centre of gravity of each group.

The saving of labour by neglecting the positions of the component members of the spot-groups and confining all determinations of position to those of spot-groups considered as complete entities is obvious. But it is necessary to inquire whether there is any corresponding loss, and, if so, to what it amounts.

It must be admitted that no use has yet been made, and probably no use could be made, of the positions determined for many of the smaller and less stable members of complex groups. On the other hand, some groups are so simple that no appreciable error arises when one of them is treated as being practically, what some are actually, a single spot. But it also happens that a group may contain members, either individual spots or subordinate clusters, which can be identified for several days in succession; it is, indeed, a frequent occurrence for a group to take the form of a number of spots arranged nearly along a parallel of latitude—a "stream," in fact,—of which the leader and last spots are the largest and most stable members, and their respective identities, day after day, are quite unmistakable. If the entire group as a whole is alone represented in the measures published, then all evidence as to the changes in position and size of these well-marked individual spots will be lost, and all the light which it might throw on the internal activities of the group.

The present paper proposes, therefore, to illustrate in diagram form the life-history of some of the more important individual spots of the year 1915; spots which have been of sufficient stability to be traced for three or more days in succession, and have been indicated in the *Journal* by a distinguishing letter in addition to the reference number of their group.

These lettered spots are obviously only found in groups of considerable duration. But of the 476 groups registered in the year 1915, 312 lasted only for one or two days, or were intermittent in appearance. Those lasting for more than 6 days numbered 100. But in many of these the smaller members were so small as to be practically negligible; the lettered chief-spot could be taken, without serious error, as comprising the whole group. Groups, therefore, in which the lettered spots give much information as to the relative changes taking place within the group are not very numerous; but 21 have been selected as fairly representative.

For these 21 groups the changes in heliographic latitude and longitude and in area have been represented in 20 diagrams, in which the abscissæ denote the successive days of observation—or the longitude from the central meridian of the sun—and the

ordinates, heliographic latitude, heliographic longitude, and area corrected for foreshortening respectively. The scale adopted is the same for one day of observation as for one degree of latitude or longitude, or for 100 millionths of the sun's visible hemisphere in area.

The maximum length of time that a spot can, under ordinary conditions, be seen during one apparition is just 14 days; this interval taking it from very close to the east limb to very close to the west limb; more generally it is seen on only 13 or 12 days. The vertical edges of the diagrams represent the east and west limbs, the broken vertical line down the centre the central meridian of the Sun.

Upward movement on the diagram represents northward movement in latitude, westward movement in longitude, and increase in area. Observations of an individual spot are joined by thin lines; those of the entire group by broader lines.

Description of the Diagrams.

Group 7127. A group that has evidently formed very shortly before it is first seen as a small cluster just within the east limb. The cluster develops quickly, and by Jan. 3—the 4th day of observation—two large and active spots, *a* and *b*, have formed at the two ends of the group. Note the rapid increase in area of the group from the 2nd day of observation to the 5th, the quick rush forward of *a* at first, and its gradual slackening of speed later, and the stability in latitude of both *a* and *b*.

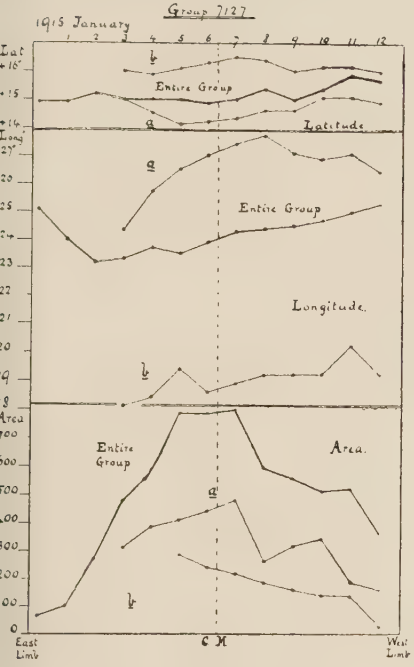
Groups 7223, 7255, and 7285. A group seen in three rotations.

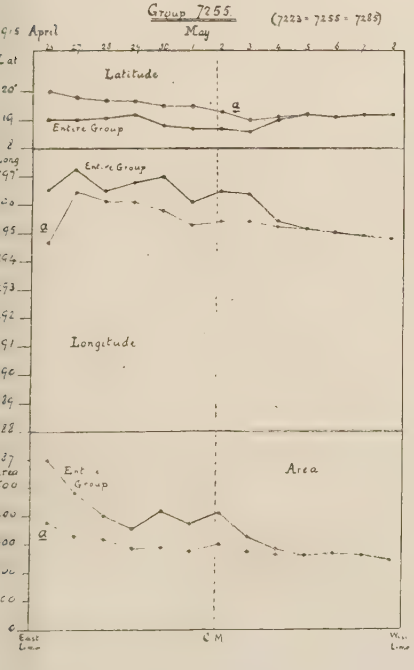
First appearance (7223). A very large spot, *a*, with a long narrow projection, *b*, on the following side. Another projection, *c*, becomes quite detached by April 5. Note the rapid rush forward in longitude of *c* until it declines in area.

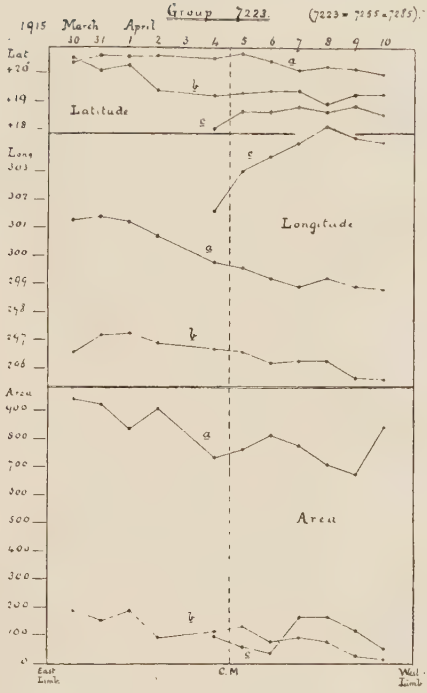
Second appearance (7255). A large regular spot, *a*, following a number of small spots in a long irregular stream. The chief spot, *a*, remains alone after May 4—the 9th day. Note the stability of *a*, and its very gradual decline in longitude and area.

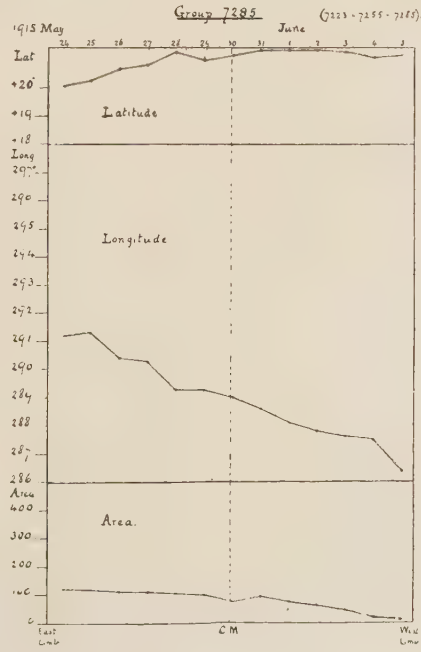
Third appearance (7285). The group now consists of a single regular spot, slowly declining in area, and moving steadily backward in longitude.

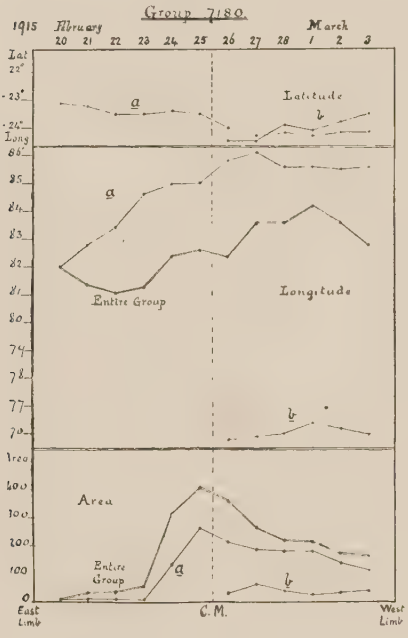
Group 7180. A single small spot, *a*, on the east limb on the first day of observation, and developing quickly from the 4th to the 6th day. It has become a regular spot by the 8th day. A considerable cluster forms in the rear of *a* from the 2nd to the 6th days, and a triple spot, *b*, has developed in this cluster by the 7th day. Note the rapid movement forward of *a* while attaining its development as a regular spot, and its steadiness in longitude later.

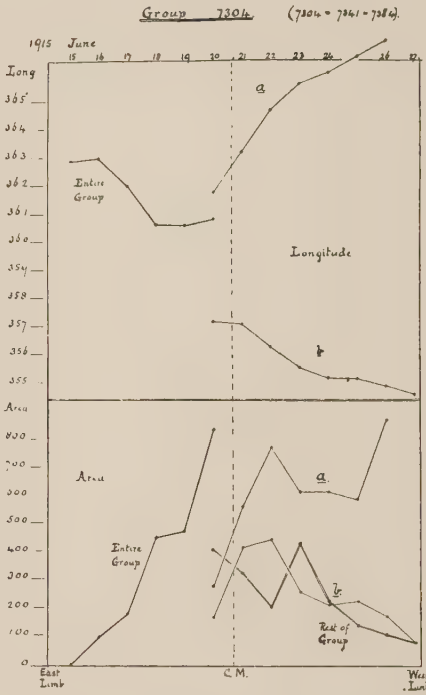

Group 7127
1915 January
Lat
Entire Group
Latitude
Long
Longitude.
Area
Entire Group
Area.
East Limb
C M
West Limb

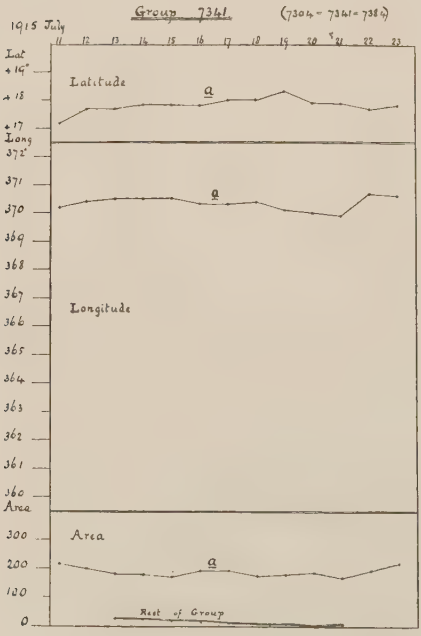

Group 7255
(7223 = 7255 = 7285)
April
May
Latitude
Entire Group
Longitude
Area
East Limb
C M
West Limb

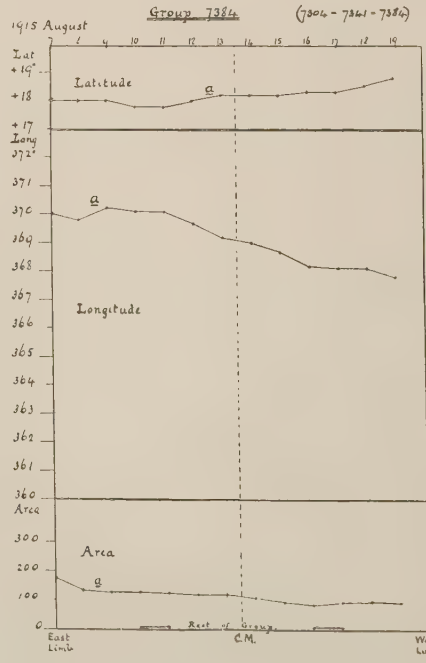

Group 7223
(7223 = 7255 = 7285).
1915 March
April
Lat
Latitude
Long
Longitude
Area
Area
East Limb
C M
West Limb


Group 7285
(7223 - 7255 - 7285).
1915 May
June
Lat
Latitude
Long
Longitude
Area
Area.
East Limb
C M
West Limb


Group 7180
1915 February March
Lat
Long
Latitude
Longitude
Area
Entire Group
East Limb
C.M.
West Limb


Group 7304 (7304 = 7341 + 7384).
1915 June
Long
Area
Entire Group
Rest of Group
East Limb
C.M.
West Limb


Group 7341 (7304 = 7341 + 7384)
1915 July
Lat
Long
Latitude
Longitude
Area
Rest of Group


Group 7384 (7304 = 7341 + 7384)
1915 August
Lat
Long
Latitude
Longitude
Area
Rest of Group
East Limb
C.M.
West Limb

SCANNED

Groups 7304, 7341, and 7384. A group seen in three rotations.

First appearance (7304). Latitude is not shown in this diagram, as the curves for longitude and area left no space for it. The spots were, however, stable in latitude, so the omission of the curves was of no importance.

A very small spot when first seen, quickly developing into a very large cluster with two chief spots, *a* and *b*. These two spots move apart, *a* moving forward and *b* backward, but more slowly, until the group has stretched out over 12° of longitude.

Second appearance (7341). A large regular spot, *a*, with a few very small companions. *a* remains very steady in latitude, longitude, and area.

Third appearance (7384). Practically a single large regular spot, slowly diminishing in size, retrograding in longitude, and moving away from the equator—*i.e.* northward—in latitude.

Groups 7306 and 7330. A group seen in two rotations.

First appearance (7306). A very small spot, which has expanded by the 2nd day of observation into a small stream of normal type, of which *a* and *b* are the leader and rearguard respectively.

Second appearance (7330). A large regular spot, *a*, followed by an extensive shaded area in which three chief spots, *b*, *c*, and *d*, are recognised on the 2nd and 3rd days of observation. By the 4th day *a* and *b* have coalesced to form *e*, and *c* and *d* to form *f*. After this both *e* and *f* retrograde in longitude and decline in area, the changes in *f* being greater than those in *e*.

Groups 7315 and 7343. A group seen in two rotations.

First appearance (7315). Two very small spots, *a* and *b*, on the first day of observation. *b* disappears before the 3rd day, but the group develops into a sparse stream with *a* and *c* as the two chief members—leader and rearguard; *a* and *c* increase in size, *a* advancing rapidly in longitude and *c* retrograding.

Second appearance (7343). Practically a single spot, *a*, which is stable in area, retrograding in longitude and moving from the equator—northward—in latitude.

Group 7299. A large complex and irregular cluster, developing into a straight stream, of which *a*, *c*, and *b* are the principal members.

The longitudes throughout these diagrams have been computed on the basis of Carrington's mean rotation-period of the Sun, viz. 25·38 days. As this particular group lies almost on the equator, where the rotation is shortest, the longitudes are also shown as given by the mean rotation-period for latitude +1°·85; *i.e.* for the mean latitude of the group, and are distinguished by being

lettered *a'*, *b'*, and *c'*, and joined by broken instead of continuous lines.

Group 7379. A sparse straight stream, of which the chief spot, *a*, is in the middle. The spots preceding *a* are treated as a single object and lettered *b*; those following *a* are similarly treated and lettered *c*. Note the apparent irregularity in the longitude of the entire group, due simply to the fact that *c* fades out a day before *b*, and *b* a day before *a*.

Group 7397. An irregular cluster speedily developing into a stream of normal type.

Note the rapid forward motion of the leader, *a*, and its sudden check as the spot ceases to increase in size. Note also that the sudden decline in the longitude of the entire group is due to the increase in area of small spots in the rear of *a*.

The group returned as No. 7438, but is not represented.

Group 7420. Example of an intermittent group. The group consists of a single small spot on Sept. 1–4, which is not seen on Sept. 5–6, but has reappeared exactly in its former place by Sept. 7. Two new spots, *b* and *c*, are also seen north of *a* on Sept. 7, and *b*, the leader, moves forward in longitude.

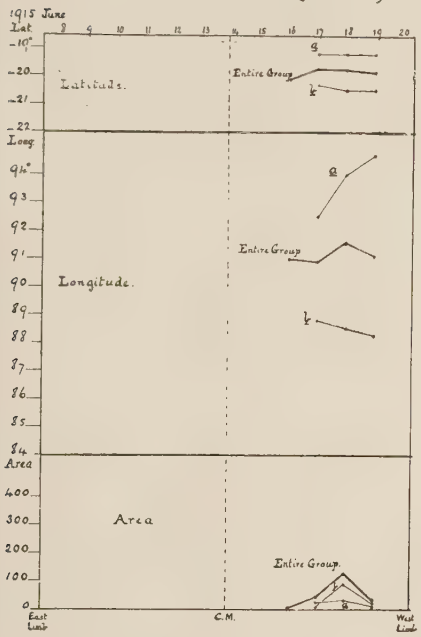
Groups 7354 and 7393. A group seen in two rotations.

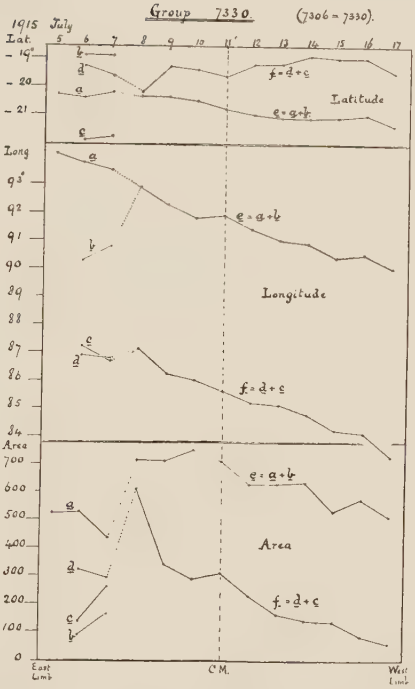
First appearance (7354). A highly complex group, containing eleven "lettered" spots, of which only those in the front of the group can be represented in the diagram. The leader, *a*, is a very large regular spot, followed by three others, and the group has become by July 24 a very long, straight, and almost continuous stream. The leader, *a*, has divided into two portions, *k* and *l*, by July 27. Note the rush forward of *a* while increasing in size, its check when its growth has ceased, and the new forward movement after the division has taken place.

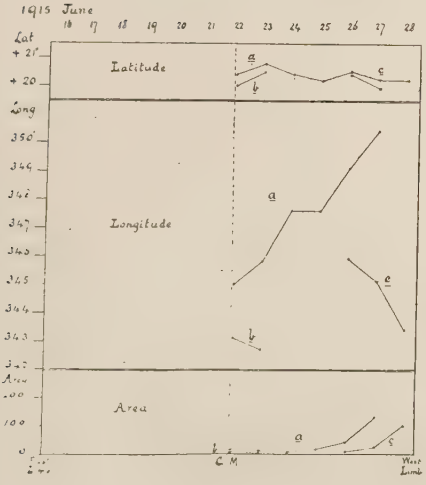
Second appearance (7393). A compact cluster, soon condensing into two large composite spots, *a* and *b*, of which *a*, the leader, develops the later. Both spots retrograde steadily.

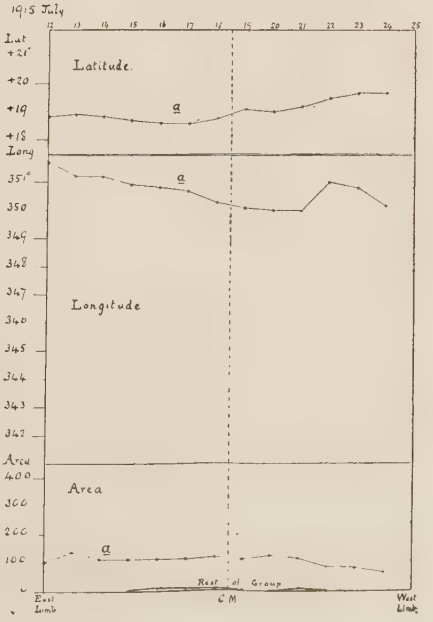
Group 7492. A typical case of the formation of a small stream, except in the early break up of the leader, *a*. The leader, *a*, moves forward rapidly in longitude until Nov. 3, after which it retreats and diminishes in size. The rear spot, *b*, retrogrades until Nov. 4, after which it increases in size and advances in longitude. The apparent irregularity of the movement in longitude of the entire group is due to this transfer of the chief activity from *a* to *b*.

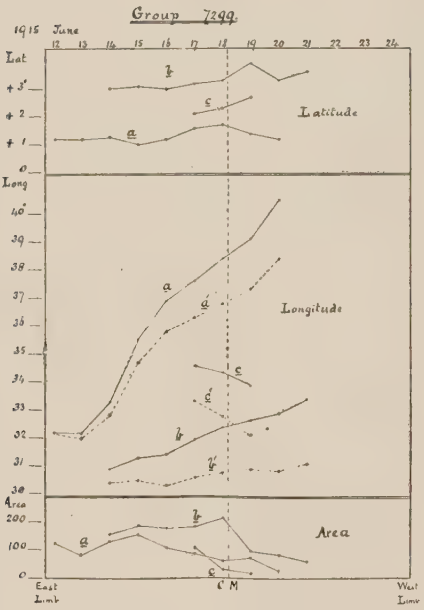
Groups 7495 and 7531. A group seen in two rotations, the formation being observed in the first, the dissolution in the second.

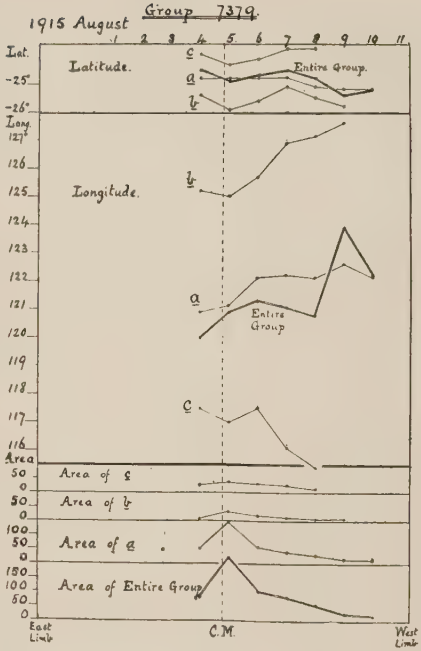

Group 7306 (7306 - 7380).
1915 June
Lat
Latitude.
Entire Group
Long
Longitude.
Entire Group
Area
Area
Entire Group
East Limb
C.M.
West Limb

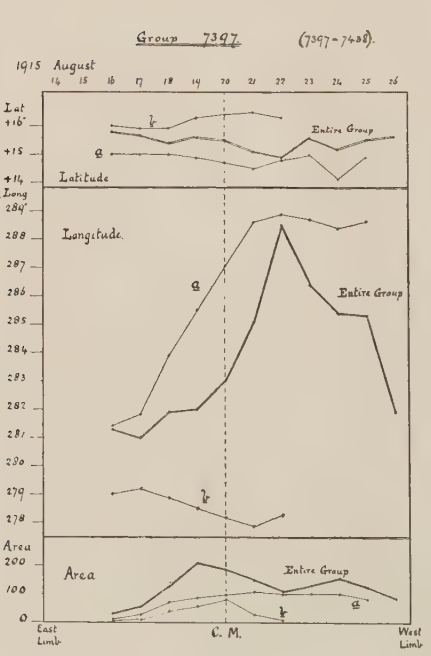

Group 7330 (7306 - 7330).
1915 July
Lat
Latitude
Long
Longitude
Area
Area
East Limb
C.M.
West Limb

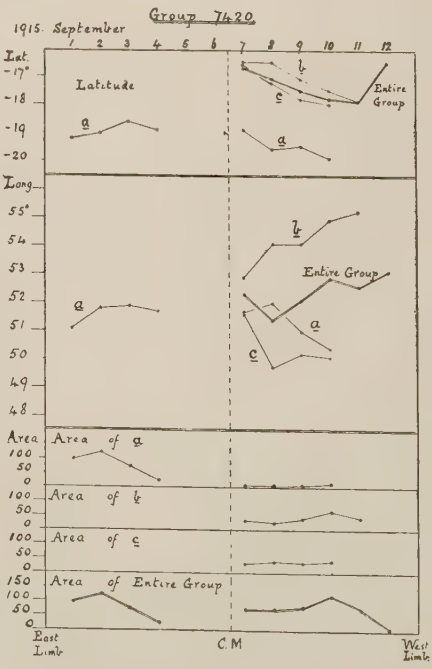

Group 7315 (7315 - 7343).
1915 June
Lat
Latitude
Long
Longitude
Area
Area
C.M.
West Limb


Group 7343. (7315 - 7343)
1915 July
Lat
Latitude.
Long
Longitude
Area
Area
Rest of Group
East Limb
C.M.
West Limb


Group 7299
1915 June
Lat
Latitude
Long
Longitude
Area
East Limb
C M
West Limb


1915 August
Group 7379
Lat.
Latitude.
Entire Group.
Long.
Longitude.
Entire Group
Area
Area of a
Area of b
Area of c
Area of Entire Group
East Limb
C.M.
West Limb


Group 7397 (7397-7408).
1915 August
Lat
Latitude
Entire Group
Long
Longitude.
Area
Area
East Limb
C. M.
West Limb


Group 7420
1915 September
Lat.
Latitude
Entire Group
Long.
Area of a
Area of b
Area of c
Area of Entire Group
East Limb
C.M
West Limb

First appearance (7495). A short stream of ordinary type, the leader, *a*, advancing in longitude; the rear spot, *b*, retrograding.

Second appearance (7531). A single small spot, apparently identical with *b* of Group 7495.

An examination of these diagrams shows that a remarkable action takes place in the early history of several of the principal groups. Two chief spots become distinguishable while the group is still small, of which the one preceding in longitude—the "leader"—moves forward in longitude for several successive days, but with diminishing speed. The rear-spot, on the contrary, retrogrades, or remains stationary in longitude; so that the distance between these two spots increases, and the group lengthens out. The average length of a fully-developed group of this type is from 10° to 12°.

The leader-spot increases in area and advances in longitude for a few days, the two changes, in most cases, coming to an end about the same time. The halt of the advance in longitude is, in some instances, very sudden; Group 7397 being a well-marked example.

After the halt of the leader the decay of the group sets in, but the process is much slower than the growth. The members of the group disappear with the exception of the leader, which generally becomes circular and strongly defined, stable in area, and with a tendency to a slow retrogression in longitude. Group 7304 in its three appearances illustrates the type.

The difficulty in detecting and correlating these internal changes in spot-groups lies in the fact that a group is seen completely for only 12 or 13 days in succession at most, while its life-history is often many times as long. Thus Group 7495, which, returned as Group 7531, lasted for 25 days, but was visible only for 10 days: 6 days near the West limb at the beginning of its activity, 4 days near the East limb as it was dying out. The full course of the changes of a group can therefore very seldom be observed throughout, unless the group be of short duration, and its entire life-history chances to fall within the fortnight or less during which the group is located within the hemisphere of the Sun that is turned towards the Earth. The records for groups of longer duration are necessarily broken, in many cases much broken, and broken in varying relationship to the critical points of their history. It is, therefore, only by the collation of a large number of life-histories of these fully-developed groups containing spots that can be identified individually that there is any prospect of increasing our knowledge of the internal activities of groups; and from this point of view it would seem to be a mistake if the practice of publishing the positions of the individual members of the groups were to be given up.

The accompanying diagrams have been drawn mainly in order to show the relative movements in longitude of members of the

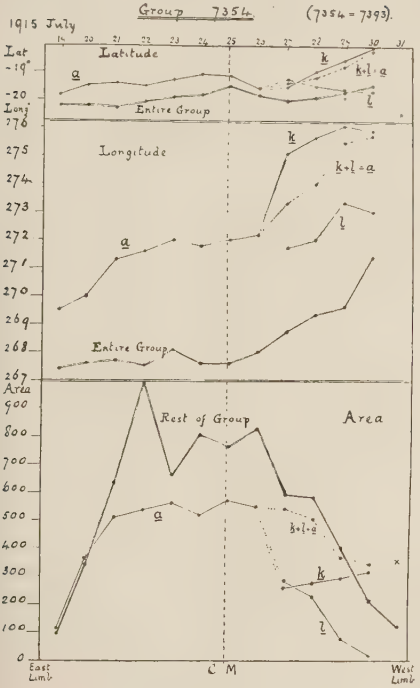
same group, as such movements most readily attract attention. But relative movements in latitude, though smaller in amount, and apparently of less regularity in character, are also often shown, and offer a field for inquiry as to whether they also may not yield evidence of a direct connection with the course of development of the group in which they take place.

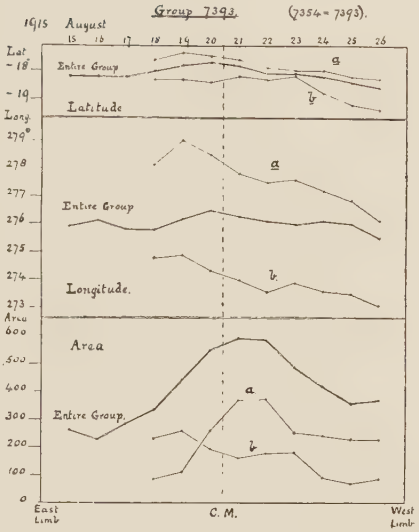
Further, even very small and transient spots are sometimes of importance as indicating the boundaries of different groups. During periods of great disturbance of the solar surface it is often very difficult to ascertain where the dividing lines between two or three neighbouring groups ought to be drawn, or whether an extended area of disturbance should be treated as a single group or as several. Evidently that mode of grouping is the most convenient, and probably the best founded, which gives the most consistent results for the positions and areas of the several groups as defined by it. Thus, again, the separate measurement of the several components of each group would appear to be a necessity, though it would not necessarily follow that every such measure should be completely reduced, or that the result of every such individual reduction should be printed and published in full.

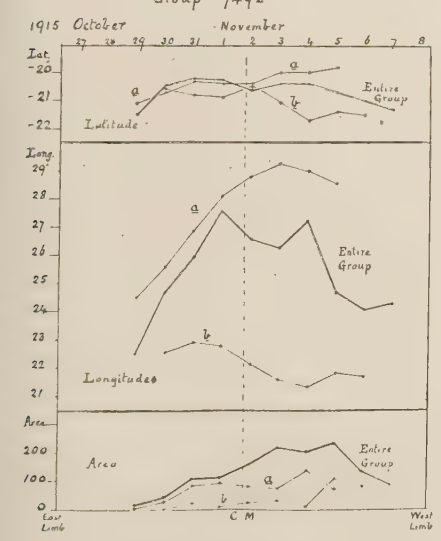
Probably the most economical, and, at the same time, efficient course, would be to follow the precedent already adopted with the solar photographs for the year 1916. For 1915 and all earlier years the position adopted for any group on a particular day was that of the "centre of gravity" of its component members, derived from the separate positions of the various members by taking their mean, weighted according to the area of each member. But for 1916 the "centre of gravity" of each group was determined directly at the micrometer; estimation by eye taking the place of arithmetical computation. This method effected a great saving of labour without any serious loss of precision.

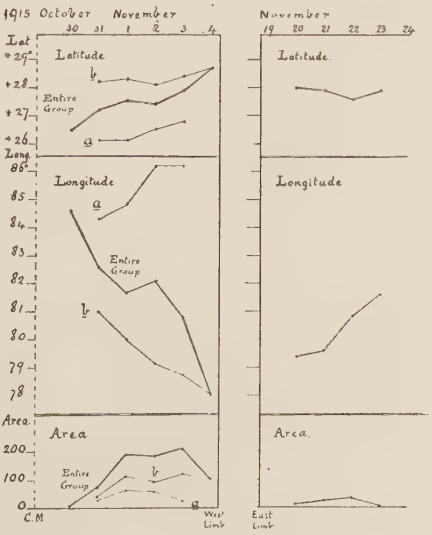
But, in addition, it will be necessary to reduce the measures of the individual components of the spot-groups of 1916—all of which have been already made,—at least as far as those spots are concerned which, from their length of duration, movements, size, or position, appear likely to afford information as to the boundaries of a group or its internal activities. This step appears to be the next one that requires to be taken; after which the question would come under consideration as to how the resulting information can be expressed most clearly and concisely in the printed *Results*.

8 *Maze Hill, London, S.E.* 10:
1919 *March* 8.


Group 7354
(7354 = 7393).
1915 July
Latitude
Longitude
Entire Group
Rest of Group
Area
East Limb
C M
West Limb


Group 7393
(7354 = 7393).
1915 August
Entire Group
Latitude
Longitude.
Area
East Limb
C. M.
West Limb


Group 7492
1915 October
November
Latitude
Longitude
Area
Entire Group
East Limb
C M
West Limb


Group 7495
Group 7531.
1915 October
November
Latitude
Longitude
Area
Entire Group
C.M
West Limb
East Limb

Note on a Remarkable Change in the South Tropical Region of Jupiter. By Rev. T. E. R. Phillips, M.A. (Plate 12.)

A rapid change of an unusually striking character and of great extent has been in progress in the southern hemisphere of Jupiter during the last few months, and, since it includes the almost total disappearance of the great *S. Tropical Disturbance* and *Red Spot Hollow*, it seems desirable that a short account of it should be published without delay.

1. As regards the *S. Tropical Disturbance*, the general nature of the changes may be gathered from the accompanying sketches. Figs. 1 and 2 illustrate the aspect of its *p* and *f* ends during the 1917–18 apparition, and it will be seen that, although in its middle longitudes the Disturbance was then only moderately dark, its extremities were very strongly and clearly defined. This characteristic persisted during the earlier part of the current apparition, and fig. 4 shows the *p* end very dark when advancing on the disc on 1918 November 15. The part of the Disturbance in front of the Red Spot Hollow is also fairly dark in fig. 3.

The first note I have of the coming change is the remark "becoming fainter" in an entry relating to an observation of the *p* end on 1919 January 9. On January 17 the *Disturbance* generally seemed slightly feebler than the *Red Spot*, and four nights later I have the note: "Part of S. Trop. Dist. now on disc exceedingly faint." On February 10 I thought the *p* end slightly darker again, but since then I have not been able to observe it when near the central meridian, and lately I have scarcely seen it at all. Cloudy weather has, of course, greatly interfered with observations, but if the *p* end still exists it must be extremely feeble.

The *f* end of the *Disturbance* has also faded, but rather less rapidly. It was certainly faint by the middle of February, and on March 9 I have the entry: "Very vague and indefinite" (fig. 6). Recently it has required to be carefully looked for under fairly good conditions to be seen at all, and were its position not indicated by a very dark streak on the S. component of the *S. Equatorial Belt* (figs. 6 and 7) it would probably have escaped notice a fortnight or so ago.

The middle part of the *Disturbance* has also shared in the extraordinary faintness of the two ends, and at the present time only a few feeble mottlings remain of what during the past eighteen years has been one of the most conspicuous features of the disc, and which recently extended over more than 180° of longitude!

2. *Region of the Great Red Spot.*—The *Red Spot* has been in conjunction with the *S. Tropical Disturbance* since the late summer of 1917. Some years ago these conjunctions occurred at intervals of a little more than two years and lasted a comparatively short

time, but the rotation periods of the two objects have been gradually approaching one another in value (*M.N.*, 68, 630), and as the *Disturbance* has also become enormously extended in longitude, its passage past the *Red Spot* is now a very protracted process.

As on previous occasions, the dark material somehow got round the *Red Spot* without obliterating or concealing it, and fig. 3 shows the hollow in which the spot lies strongly and clearly defined. The darker *f* end of the spot is also seen, but a little later the complete ellipse became visible with clear spaces separating its *p* and *f* ends from the *Disturbance*. The growth of the white area *following* the *Red Spot* and its apparent repulsion of the dark matter of the *Disturbance* was a striking feature of the last apparition, and it is still clearly though faintly shown in figs. 3, 5, and 6. During the last few weeks, however, this region has so faded as to be almost unrecognisable, and the *Red Spot* itself has not been wholly exempt from change. In fig. 5 its outline appears somewhat distorted; in figs. 6 and 7 only the darker portion is shown; but in the drawing of April 2 (fig. 8) the complete elliptical form is again seen, though part of it is very faint and difficult.

But there is nothing remarkable in the recent faintness of the *Red Spot*. What is far more striking is the disappearance of the well-known hollow in which it lies. The spot is close to the central meridian in figs. 3, 5, and 8, but whereas in the first of these the *p* shoulder is exceedingly dark and prominent, it is of the feeblest description in figs. 5 and 7, and only by means of the closest scrutiny could I detect it at all. The *f* shoulder I have not been able to distinguish lately from the *f* end of the spot, and hence the *Red Spot Hollow* which for many years past has been a conspicuous landmark on Jupiter, even when the spot itself has been invisible or imperfectly seen, is seemingly accompanying the *S. Tropical Disturbance* into invisibility!

And the same thing is true of the entire S. component of the *S. Equatorial Belt*. Here and there short dark streaks have remained for a while, and one or two can still be observed, but as a whole this part of the belt has become very feeble indeed.

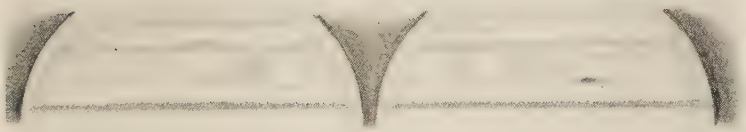
But while this general enfeeblement has marked the S. tropical latitudes of the planet, increased activity has been observed in neighbouring regions. Further south—on the *S. Temperate Zone* and *S.S. Temperate Belt*—there has developed a new disturbance, and the idea has been suggested that it may perhaps have grown at the expense of that now apparently dying. The equatorial zone has also become much darker of late—it is now decidedly darker than the central parts of the *S. Equatorial Belt* and *S. Tropical Zone*,—and the changes above described, together with the remarkable breadth and strength of the great Northern belt, have given to the planet a very different appearance from that to which we have grown accustomed. It is, of course, too soon to say that all these changes are more than temporary. They

1. 1917 Dec. 19.

2. 1917 Dec. 19.

3. 1918 Oct. 13.

4. 1918 Nov. 21.



5. 1919 March 2.

6. 1919 March 9.

7. 1919 March 24.

8. 1919 April 2.

Changes in S. Tropical Disturbance and Red Spot region of Jupiter.

may be due in part to mist or cloud overlying familiar features, but I think not. At any rate it is a cause for satisfaction that the phenomena described should have occurred with the planet so favourably placed for observation; and, together with the remarkable white spots to which Mr. Sargent has drawn attention (*M.N.*, 79, 208), they have made the apparition of 1918–19 a truly memorable one.

Headley Rectory, Epsom:
1919 *April* 10.

On the Fifteen-Month Periodicity in Earthquake Phenomena.
By H. H. Turner, D.Sc., F.R.S., Savilian Professor.

1. In the Report of the Seismology Committee to the British Association in 1912 evidence is given for the existence of a periodicity of nearly 15 months (there identified as 104/7 months) deduced from the *Catalogue of Destructive Earthquakes* compiled under Milne's superintendence. It was natural to examine the independent *Catalogue of Chinese Earthquakes* compiled by Milne's Japanese assistant, Shinobu Hirota, and published in the Seismology Report for 1908 (Section XI.), with additions by Prof. E. H. Parker in 1909 (Section XII.). This examination was started some time ago, but owing to various causes not completed until recently, when the transference of Miss E. F. Bellamy to the Seismological service provided the opportunity.

2. In Table I. are given:

In the first column the approximate initial dates of twenty consecutive periods of about 79 years, each containing exactly $15 \times 7 \times 9$ months, or 63 cycles of 15 months. The cycle was identified (in the B.A. Report for 1912) as of 104/7 months, which can be approximately dealt with either

(*a*) by repeating a month at the end of seven complete sets of 15 months ($7 \times 15 = 105$), or
(*b*) by collecting sets of 15 months in sevens without repetition and then shifting the initial month one to the right for each set.

The first method (*a*) was adopted in the 1912 Report. As a variant, the second method was adopted here. Hence the initial month, if it is to remain in step with the cycle, can only be indicated approximately.

TABLE I.

Approx. Initial Date.		No. of Quakes.	15R.	θ_0.	Add.	θ_1.
285	May	59	25	180°	−122	+ 58
364	Aug.	29	11	27	− 98	− 71
442	Aug.	5	6	11	− 74	− 63
521	Nov.	13	4	7	− 50	− 43
599	Nov.	16	11	345	− 26	− 41
679	Feb.	14	7	220	− 2	(−142)
758	May	40	29	37	+ 22	+ 59
836	May	16	6	280	+ 46	− 34
915	Aug.	8	2	180	+ 70	(−110)
993	Aug.	48	19	207	+ 94	− 59
1072	Nov.	25	6	92	+118	(−150)
1150	Nov.	38	22	210	+142	− 8
1230	Feb.	22	14	207	+166	+ 13
1309	May	108	17	220	+190	+ 50
1387	May	28	14	18	+214	(−128)
1466	Aug.	129	26	193	+238	+ 71
1544	Aug.	100	17	45	+262	− 53
1623	Nov.	75	38	94	+286	+ 20
1701	Nov.	21	19	99	+310	+ 49
1701	Feb.	16	3	40	+334	+ 14
	Total	810				

3. The second column gives the total number of earthquakes noted in the whole set of 105×9 months $= 78$ years 11 months. It will be seen that the statistics are of a kind suggesting a very imperfect record. In the third period of 79 years, for instance, only five earthquakes are recorded. There are, however, two possibilities which may mitigate the imperfection:

(α) This period may have been really quiescent. We note small numbers in the 3rd, 9th, 15th, and 20th periods, which are consistent with a systematic variation. Against this must be set the fact that the numbers adjacent to the 15th period are the largest in the series. The evidence is, in fact, insufficient to settle this point.

(β) If the five earthquakes recorded attracted special attention among minor ones, they may still indicate periods of special activity, so far as they go.

4. The third and fourth columns give the results of harmonic analysis of the 15-month term in each set of 79 years. The real variable is, however, the number of earthquakes per month, which, by giving totals in the preceding column, is necessarily multiplied by 15. Hence the coefficient R has also been multiplied

by 15 for readier comparison. The phase θ_0 in the fourth column shows a slow diminution which can be approximately corrected by successive additions of 24°, as shown in the fifth and sixth columns: corresponding to a further shortening of the adopted period by 1 month every 79 years. The adopted period thus becomes

$$(63 \times 15 - 10)/63 \text{ months},$$
$$= 14{\cdot}84127 \text{ months},$$
$$= 451{\cdot}7111 \text{ days}.$$

5. If we make the corresponding arrangement of the numbers analysed, shifting the whole set one to the right for each set of 79 years, and add together the results, we get totals as in Table III. To show the accordance the whole material of 20 sets of 79 years has been divided into four parts of $5 \times 79 = 395$ years each, which have been separately analysed, as in Table II.

TABLE II.

A.D.	Totals.	15R.
285–680	122	$31 \cos(\theta - 114°)$
681–1075	126	$23 \cos(\theta - 119°)$
1076–1470	221	$34 \cos(\theta - 126°)$
1471–1865	341	$83 \cos(\theta - 154°)$

TABLE III.

Number of Chinese Earthquakes.

A. D. 285–680.	681–1075.	1076–1470.	1471–1865.	Total.	Smoothed.
7	5	20	18	50	47
4	14	13	18	49	55
15	13	13	25	66	58
12	6	18	24	60	63
11	7	17	28	63	57
9	6	11	22	48	58
6	7	24	25	62	60
9	19	13	28	69	65
9	10	13	33	65	63
8	7	17	23	55	58
6	5	18	24	53	54
10	8	13	24	55	49
10	6	10	14	40	42
2	6	7	17	32	38
4	7	14	18	43	42
122	126	221	341	810	

6. In the last column of Table III. means of every consecutive three totals are taken to reduce accidental errors. The range of variation is shown by the harmonic analysis to be over 40 per cent.,

and this is confirmed by Table III.; we can scarcely put the maximum lower than 60 or the minimum higher than 40.

7. We have still to assess the exact period, for both Tables I. and the harmonic analysis of Table II. show that the allowance of one whole month every 79 years is only approximately correct. There is an advance in phase meaning that the adopted period is now rather too short. The series of phases 114°, 119°, 126°, 154° for successive sets of $5 \times 9 \times 7 = 315$ cycles suggest as limits for the advance 6° per set if we are guided by the first three, or 28° per set if we are guided by the last two. The former lengthens the period to

$$14{\cdot}8413 + {\cdot}0008 = 14{\cdot}8421 \text{ months},$$

and the latter to

$$14{\cdot}8413 + {\cdot}0035 = 14{\cdot}8448 \text{ months}.$$

The former implies an addition of about one-twentieth of a month in the 79 years, the latter about a quarter of a month.

8. As regards the probability that this is a real periodicity and not mere coincidence, we have firstly the general accordance of the four sets of 400 years. But it is desirable to supplement this by calculating the coefficients of neighbouring periodicities. In Professor Schuster's method of the "periodogram" he tabulates the squares of the coefficients of all periodicities; but it has been shown that it is sufficient to calculate those of the Fourier sequence separated by whole wave-lengths (*M.N.*, **73**, 732). In this case the total number of cycles available is 1260, so that the successive terms of the sequence change in period by very small fractions of a month. It will suffice therefore to group a considerable number of cycles together, since an advance of one whole month is only due after $1260/15 = 84$ cycles. Calculating four successive terms of the sequence in this way we get:

TABLE IV.

Neighbouring Periodicities.

Period.	$15R \sin \theta_0$.	$15R \cos \theta_0$.	$(15R)^2$.
14·8294	+ 50	− 20	2900
14·8413	+110	−117	25789
14·8532	− 62	− 67	8333
14·8651	− 27	+ 12	873

If the true period lies between the second and third tabulated, then both $\sin \theta_0$ and $\cos \theta_0$ should there change sign. That change occurs in $\sin \theta_0$, but not in $\cos \theta_0$ until after the next term is reached. We thus have some idea of the magnitude of possible "accidental" causes.

But the rise in the value of $(15R)^2$ is fairly satisfactory.

9. The series analysed commences with the year 285 A.D., but the Catalogue goes back much earlier (actually to B.C. 1820). In the earliest years the records are, however, so imperfect that they

were omitted from the investigation. Now, however, that the period has been identified within close limits, we may see how far these early records support the other evidence. By going back to A.D. 49 we get three more 79-year sets, the analysis of which gives

(*a*) For insertion at the head of Table I.

Date.	No.	$15R$.	θ_0.	Add.	θ_1.
49 Feb.	17	7	43°	−194	(−151°)
127 Feb.	31	7	120	−170	− 50
206 Feb.	15	6	178	−146	+ 32

(*b*) For insertion at the head of Table II.

49–284 63 $7\cos(\theta - 60°)$

10. The mean epoch for these early records precedes the mean of the former by 12 sets of 79 years. The mean phase of Table II. is 128°, and comparing this with 60° we get an advance of 68°/12 in 79 years = 5°·7. In 5 sets of 79 years this becomes 29°, which lies just outside the limits of 6° and 28° assessed in § 7. But with a reasonable compromise the corrected phases would stand as below:

TABLE V.

Observed.	60°	114°	119°	126°	154°
Calc.	+78	+94	+114	+134	+144
O–C.	−18	+20	+ 5	− 8	+ 10

11. We must now compare the elements of the periodicity thus determined with those derived from the *Catalogue of Destructive Earthquakes* in the 1912 report. The discussion there was made with the time reversed, proceeding from the numerous modern records backwards to the old imperfect ones. For comparison with the present series we will reverse them, and reduce the phases to the beginning of the mean year of the various sets discussed. Thus the entry under February 1897 proceeds backwards to March 1871. The mean date is approximately 1884·0. In 1884 the adopted initial month of an exact 15-month cycle would be November (*i.e.* the middle of November), but if a month is dropped in every 105 it becomes $1\frac{1}{2}$ months earlier, just 9 months, or 216°, later than 1884·0. Hence the maximum falls at 48° + 216° = 264°.

12. In Table I. we have a set of 78 years, commencing with February in 1230, to which a similar calculation applies. Since it is the 13th set, the initial month would still be February when one month per set is subtracted, as for Tables II. and III. The theoretical phase for this set, calculated as in § 10, is 134°; which, when corrected to 1269·0, becomes 134° + 216° = 350°, which we may thus take as our starting-point. The advance is closely 69°·00 per year, adopting which gives the advance in 26 years as 1794° = 1800° − 6°.

TABLE VI.

Comparison with "Destructive" Earthquakes.

Initial Date.		Phases.					
Old.	New.	Old, Reversed.	Corr.	New.	Chinese.	N–C.	Corrected.
		°	°	°	°	°	°
1377 F	1338·0	− 13	+216	203	81	(−238)	−188)
1455 F	1416·0	+ 62	+216	278	63	(−145)	(− 95)
1533 F	1494·0	− 10	+216	206	45	(−199)	(−149)
1611 F	1572·0	+ 23	+216	239	27	(−148)	(− 98)
1689 F	1650·0	+118	+216	334	9	− 35	+ 15
1767 F	1728·0	+149	+216	5	351	+ 14	+ 64
1793 F	1780·0	+ 20	+216	236	345	−109	− 59
1819 F	1806·0	+ 36	+216	252	339	− 87	− 37
1845 F	1832·0	+113	+216	329	333	− 4	+ 46
1871 F	1858·0	+ 19	+216	235	327	− 72	− 22
1897 F	1884·0	+ 48	+216	264	321	− 57	− 7
1905 O	1901·0	+ 24	− 48	336	54	− 78	− 28
1909 Jn	1908·0	−145	− 67	148	177	− 29	+ 21

13. There is apparently a systematic difference between the two records of some 50°, allowance for which (as in the last column) brings them into accord from 1689 onwards. It is, perhaps, not surprising that the earlier records are discordant, though it seems probable that the discordance is in the "Destructive" Catalogue and not in the Chinese. For the period deduced from their patient work brings into accord the last set above (first in 1912 Report), which was formerly discordant.

14. But it seems probable also that we have as yet only got a partial truth. From 1767 we have a comparison every 26 years, and the last column shows the sequence:

$$+64-59-37$$
$$+46-22-7$$
$$(+21),$$

the +21 being possibly a hint of the coming positive term due in 1923 according to the sequence. Is there a variation within 79 years? This was suspected before this comparison was made. Take, for instance, the total number of earthquakes in the nine sets of 105 months into which every 79 years is divisible. Adding up corresponding totals we get for the whole material (1600 years):

Set	A.	B.	C.	D.	E.	F.	G.	H.	K.
Total	98	108	98	115	84	92	71	64	75

The variation is considerable, and may be represented by

$$88+20\cos(\theta-84^\circ).$$

The phases of the 15-month term also show variations in the same cycle of 78 years. Further, a cycle of approximately 40 years has been noticed in various other phenomena. These points call for further investigation, which is proceeding.